Author:
Becci, Stella Lucia

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Self-Referential Biases on Attention and Memory triggered by Object Ownership

Self-Referential Biases on Attention and Memory triggered by Object Ownership

Stella Lucia Becci

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Abstract

Self-referential processing has been argued to hold a unique status in cognition. Self-referred information benefits from attentional biases which might facilitate its elaboration and retention. The present enquiry investigates self-referential biases on attention and memory, triggered by object ownership. In a first experiment, participants sorted shopping items as either belonging to self or other, guided by ownership cues; memory for the items was later measured with an old-new test. ERPs were recorded during both the sorting and test phases. More self-owned items were recognised, adding to the evidence that encoding items within an implicit self-referential context facilitates their retention. An attentional bias was elicited by self-ownership cues, as measured by a larger P300 component, replicating previous findings (Turk et al., 2011). This difference in P300 persisted amongst subsequently recognised items, suggesting a contribution of the self-attentional bias to qualitative aspects of memory that were not behaviourally measured. Ownership modulated the late old-new effect, with a larger LPC observed for recognised self-owned items, possibly indexing the enhancement of recollection by self-reference. To investigate this possibility, a further ERP experiment was designed which employs a remember-know task during the memory phase of the shopping paradigm, to dissociate between recollection and familiarity-based recognition. The ERP-viability of this design was tested in a second behavioural experiment. More self-owned items were recollected, suggesting self-referential encoding enhances recollection specifically (van den Bos et al., 2010). Insufficient numbers of remember responses indicated the design would not be viable in an ERP experiment. Whether self-other differences seen in the ERPs in the present enquiry can be accounted for solely by differences in activity of regions involved in episodic memory retrieval, or also by activation of self-specific brain structures, remains to be further investigated by future enquiries. The potential application of self-reference to the enhancement of learning is discussed.

Keywords: self-reference, attention, memory, object ownership, event-related potentials.

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Author’s declaration

I declare that the work in this dissertation was carried out in accordance with the requirements of the University's *Regulations and Code of Practice for Research Degree Programmes* and that it has not been submitted for any other academic award. Except where indicated by specific reference in the text, the work is the candidate's own work. Work done in collaboration with, or with the assistance of, others, is indicated as such. Any views expressed in the dissertation are those of the author.

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1 General Introduction

1.1 Introducing the Concept of Self

Philosophers have long discussed the concept of self, in trying to answer the metaphysical question of whether the self is real, and thus exists, or whether it is a matter of perception, something we perceive as real but, in fact, is just an illusion. As summarised by Northoff (2013), the French philosopher Descartes (1596-1650) thought the self to exist as a mental entity out of the body and outside experience, thus operating a body-mind distinction. In contrast, the Scottish philosopher Hume (1711-1766) described the self as a complex set of perceptions of events. According to the latter view, there is nothing else in reality other than the events that we perceive; in other words, the self is nothing but an illusion. The self as mere illusion is a popular stance also amongst current philosophers, who tend to side with Hume over Descartes (Northoff, 2013). If the self does not exist, how does one experience a self in the first place? As detailed by Northoff (2013, p.2), one view is that:

"[One's] own brain and body are represented as such in the neuronal activity of the brain. And such representation is the model of [one's] self. The self-model is therefore nothing but an inner model as the integrated and summarised version of … [one's] own brain and body's information processing".

The self is here seen as merely a special form of representation. Therefore, the metaphysical discussion on the self as a philosophical concept is replaced by the discussion of how the self is represented in the brain. Northoff (2013) argues that, because such self-representation arises out of the integration and summarisation of neural processes, which cannot be directly observed, it must be supported by specific higher-order cognitive functions, for example attention and memory, amongst others. The implication of this view is that the self is no longer characterised as mental entity, but as cognitive construct, therefore allowing an empirical investigation of the cognitive processes that underlie its representation. The self ceases being a metaphysical matter for philosophers to discuss and becomes instead subject of empirical investigation for cognitive psychologists and neuroscientists (Northoff, 2013).

The number of research enquiries into self-related cognitive processes has been flourishing at an astounding pace in the psychological sciences since the 1950's (Klein, 2012). Given the difficulties in formulating an account of the self per se, enquiries usually focus on the neurological and cognitive mechanisms that are involved in generating the experience of self, – what Klein (2012, p.284) defines as the "epistemological self". Science has advanced substantially in defining the cognitive and neurological bases of the epistemological self. Klein identifies the reason for this progress in that the epistemological self is empirically testable, that is, it is accessible to third-person perspective. On the contrary, the “ontological self” (Klein, 2012, p.285), or the self of subjective experience, lacks the definitional adequacy for experimental enquiry.

Klein (2012) further argues that many cognitive scientists rely on their readers’ familiarity with the concept of self in sidestepping the difficulty of defining what it is they are referring to when they use the term ‘self’, and that some may even fail to understand that the ontological self, or self as subjectivity, is not the object of their investigations. Furthermore, he argues that some contemporary philosophers, by pronouncing the self to be nothing more than an illusion, have made an attempt to exclude the ontological self from investigation, but “a simple question remains – to or for whom is the self an illusion?” (Klein, 2012, p.286).

Following Klein’s admonition to cognitive scientists, it is here defined that the investigation of the ontological self, and its (or the lack of its) existence is not amongst the aims of the present enquiry. As such, every use of the term ‘self’ from here onward will refer to what Klein defines as epistemological self, or the self of knowledge and self-representation. The present enquiry aims to empirically investigate the self as a cognitive construct by means of observing its impact on higher cognitive functions such as attention and memory, as will be seen in the following sections.

1.2 Self as a Cognitive Construct: Self-Referential Processing and the Self-Reference Effect

Another way to operate Klein’s (2012) distinction between the ontological and the epistemological self, as described in the previous section, is by distinguishing the self as subject, or the ‘I’ of experience (i.e.; ontological), and the self as object, or the ‘Me’ of self-representation of contents (i.e.; epistemological). By one definition, self-referential processing “refers to a content that is already there and established while it is linked or referred to the self” (Northoff, 2016, p.204). Because of such dependence on contents, self-referential processing can only be defined within the concept of representation-based self (Northoff, 2016), that is, the epistemological self introduced in the previous section.

Cognitive psychologists focusing on memory initially observed that information that is actively processed with reference to one’s self is better remembered than information processed in other ways. In their seminal work on ‘depth-of-processing’ (DOP), Craik and Tulving (1975) had already found that processing words for their semantic meaning makes them better remembered than words processed for their structural features. Extending this work, Rogers, Kuiper and Kirker (1977) found that evaluating trait adjectives for relevance to self (e.g., “Does the word ‘honest’ describe you?”) makes them better remembered than adjectives evaluated for their semantic meaning (e.g., "Does the word 'honest' mean the same as 'trustworthy'?"). Rogers and colleagues (1977) labelled this phenomenon the 'self-reference effect' (SRE) in memory.

In explaining the SRE, two accounts have been proposed. On the one hand, Rogers and colleagues (1977) initially suggested that the self is a "superordinate schema that contains an abstracted record of a person's past experience with personal data" (p.685), and that its cognitive structure holds special mnemonic abilities, resulting in enhanced memorability for information processed with reference to the self-schema. This account will be referred to from this point onward as the 'uniqueness account' of self-reference. On the other hand, Klein and Loftus (1988) advanced the 'elaborative/organisational account' that the self-referential memory advantage occurs as the self-construct promotes both relational (i.e., elaborative) and item-specific (i.e., organisational) representation of information. Klein and Loftus (1988) argued that self-reference is different from other memory-enhancing tasks, in that self-reference promotes both elaboration and organisation at once, resulting in the observed memory advantage. However, according to their account, self-reference is not unique; rather, the SRE is seen as an extension of the DOP effect.

The SRE has been of interest to cognitive psychologists because of its potential as a way to investigate the impact of the self on memory. This has been investigated through the use of a variety of experimental tasks and populations. In early investigations of the effect, it was soon observed that comparisons of self-referential tasks with semantic tasks was confounded, as self-reference denotes a social entity, whereas semantic tasks do not, suggesting that the memory advantage may be an artifact of the task used for comparison (Symons & Johnson, 1997). In addressing this limitation, researchers started comparing memory following self-reference (SR) to that following other-reference (OR), that is, reference to a familiar other (e.g., "Does the word 'honest' describe the current president of the United States?"). Symons and Johnson (1997) carried out a first meta-analytic review of the first two decades of SRE research, which primarily involved words as stimuli. They concluded that, overall, the hypothesis of an SRE was supported by evidence across the literature, with self-reference being more effective than comparison memory-enhancing tasks in facilitating memory in the studies which they reviewed, applying to a variety of contexts. Albeit the magnitude of the SRE was smaller for SR – OR comparisons, than in SR – semantic comparisons (mean weighted effect sizes $d_+ = 0.35$ and $d_+ = 0.65$ respectively, as reported in Symons & Johnson, 1997, p.384), the SRE occurred consistently within both manipulations classes.

On the basis of the elaborative/organisational account proposed by Klein and Loftus (1988), Symons and Johnson (1997) had hypothesised that the SRE would be smaller when the comparison task elicited both relational and item-specific processing, rather than either one or the other. Their meta-analysis revealed that the SRE was reduced, if not completely eliminated, when the other-referent used in the task was an intimate other. In contrast to this, familiarity of the other-referent did not predict the magnitude of the effect. They argued this occurs as the rating of a highly intimate other (e.g., one's mother) is a frequently occurring, thus well-practiced, task. Moreover, the SRE should decrease as the intimacy of the other increases, because rating a highly intimate other involves relational processing in which a highly organised memory domain is referenced, and item-specific processing that involves increasing degrees of elaboration as one's knowledge of the other-referent target increases. Following this, they recommended that future studies should consider intimacy of the other-referent as different from high familiarity.

Following their review of the evidence, Symons and Johnson (1997) adopted Klein and Loftus's (1988) perspective that self-reference, although not necessary, is sufficient to enhance memory. However, they further suggested that its major benefit lies not in invoking organisational and elaborative processing per se but instead in creating matching between encoding and retrieval conditions, where encoding is the initial processing of information, and retrieval is its later recognition or recall. Thus, they argued that it is this encoding-retrieval matching that distinguishes self-reference from other kinds of memory enhancement techniques. Further to this, they argued that the uniqueness of self-reference as a process is also due to the practice it receives every day, as one processes certain kinds of information with reference to oneself. In favour of this point is the observation that self-reference is most effective in facilitating memory for certain kinds of stimuli, such as trait adjectives, which are commonly organised and elaborated through reference to self.

1.2.1 Investigating Self-Referential Processing with Neuroimaging

The evaluation of the two competing theories of the uniqueness account (Rogers et al., 1977), and the elaborative/organisational account (Klein and Loftus, 1988), introduced in the previous section, is challenging by using merely behavioural measures. The advent of neuroimaging techniques further informed the understanding of self-referential processing and its supporting neural systems. Craik and colleagues (1999) were the first to investigate self-reference with positron emission tomography (PET). It had been previously documented that memory encoding processes activate left prefrontal areas, while episodic memory retrieval predominantly involves right prefrontal areas (Nyberg, Cabeza & Tulving, 1996). Following James's (1890) point that, "for a mental event to be experienced as a personal memory, the imagined event must … be referred to the past and … be associated with feelings of self" (p.650), Craik and colleagues (1999) wanted to investigate the role of self in memory retrieval, specifically whether the association of retrieval with activation of right prefrontal areas of the cortex could be attributed to self-representation in this brain region.

Participants completed a trait-adjective task in the PET scanner, in which they rated personality trait adjectives on how well they described themselves or a familiar other, with the addition of two control conditions involving semantic and syllabic judgements. Their behavioural results showed a self-reference effect, whereby participants remembered more adjectives rated in relation to themselves, versus the familiar other, and the control conditions. PET data during the encoding of adjectives showed left prefrontal activations for the self-related condition, which were similar to those for the other-related condition and the semantic control condition, suggesting that part of self-concept is represented in a similar form to other semantic knowledge. In contrast, the PET data during retrieval showed frontal activations specific to the self-related condition, compared to the other-related and the control conditions. Self-related processing predominantly activated regions in the right frontal lobe. Craik and colleagues (1999) interpreted their findings as evidence that activation of the self-concept is necessary for episodic retrieval, as supported by neural activation in the right frontal lobe, where the self-concept might be, at least partially, represented. They also acknowledged an alternative explanation, whereby self-related judgements necessarily involve retrieval of episodic instances; however, evidence that amnesic patients retain the abilities for self-assessments goes against this alternative explanation (e.g., Klein, Loftus & Kihlstrom, 1996).

Wanting to further investigate whether self-referential processing holds a unique status in the brain, Kelley and colleagues (2002) used event-related functional magnetic resonance imaging (fMRI), whilst participants made judgements on trait adjectives, as in Craik and colleagues' (1999) PET study. Previous functional imaging studies had located areas in the left frontal cortex that showed larger activation for elaborative semantic encoding of words, compared to non-semantic, surface-based encoding of words (Buckner, Kelley & Petersen, 1999). Kelley and colleagues (2002) hypothesised that, if the SRE is an extension of ordinary semantic memory processes, as argued by Klein and Loftus (1988), then they would expect to find larger activation for self-relevant judgements in those left frontal areas found to be specifically involved in semantic encoding. Otherwise, if the SRE results from the uniqueness of the self as cognitive construct (Rogers et al., 1977), then they should be able to observe selective engagement of other brain regions during self-relevant judgements.

Behavioural results showed a self-reference effect, with more adjectives remembered when judged for self-relevance, than for other-relevance. The left inferior frontal cortex and the anterior cingulate cortex (ACC) were selectively activated during semantic judgements versus structural judgements. However, self-related judgements did not result in a larger activation of left frontal regions. This result provides evidence against the elaborative/organisational hypothesis that the SRE is an extension of the DOP (Klein & Loftus, 1988). Further to this, selective activation of the medial prefrontal cortex (MPFC) by self-related judgements was found, consistent also with Craik and colleagues' (1999) findings. Moreover, unlike Craik and colleagues who used a blocked-design paradigm, whereby a number of same-type trials are presented in succession, in Kelley and colleagues' (2002) paradigm trial types were intermixed randomly, thus allowing an examination of item-related activity in isolation (rather than in a block). As such, their results were the first to directly associate activity in the MPFC to self-relevant judgements. Kelley and colleagues (2002) concluded that their study provided further functional imaging evidence for the uniqueness account of self-referential processing, and suggested the MPFC as a neural substrate for the SRE in memory. In the following section, more neuroimaging evidence will be discussed, with the aim to provide an overview of the neural systems supporting self-referential processing.

1.3 Neural Systems supporting Self-Referential Processing

1.3.1 Cortical Midline Structures and the Rest-Self Overlap

Northoff and colleagues (2006) conducted a meta-analysis of 27 PET and fMRI studies on self-related tasks employing a variety of stimuli, such as trait adjectives, memories, emotions and movements, all published in the early 2000's. Their aim was to investigate whether activation observed in a set of structures known as cortical midline structures (CMS; see Figure 1.1) when processing self-related material, is specific to self-referential processing, or can be accounted for by other sensory/perceptual processes supporting the tasks used, as hypothesised in a critical review by Gillihan and Farah (2005). Their findings revealed a set of regions within the extended CMS which are activated during self-referential processing. This activation occurred independently of sensory modality, and such sensory independence could be observed in all domains. This led Northoff and colleagues (2006) to advance that neural processing in CMS might be characterised by "supramodality" (p.449), that is, independence from the modality of the task used. They further justified their claim by noting how CMS receive afferent connections from all exteroceptive sensory modalities (olfactory, gustatory, somatosensory, auditory, visual). In addition, they also noted that CMS are densely connected to cortical and subcortical regions (insula and brain stem regions) processing interoceptive sensory signals. Given said connections to sensory regions, and the abovementioned supramodality, Northoff and colleagues (2006) suggested that the CMS "might provide the anatomical ground for directly assessing the different sensory stimuli according to their degree of self-referentiality" (p.449); however, they also noted that the mechanisms by which this occurs are unclear and need further investigation. Nevertheless, their meta-analysis provides strong evidence for the CMS as a self-specific anatomical unit.

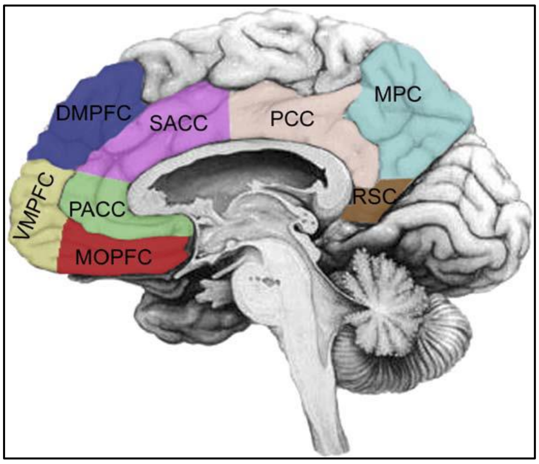

Figure 1.1 Schematic illustration of cortical midline structures (CMS). The regions referred to as CMS include: MOPFC = medial orbital prefrontal cortex; VMPFC = ventromedial prefrontal cortex; PACC = perigenual anterior cingulate cortex; SACC = supragenual anterior cingulate cortex; DMPFC = dorsomedial prefrontal cortex; MPC = medial parietal cortex; PCC = posterior cingulate cortex; RSC = retrosplenial cortex. Reproduced from Northoff et al. (2006, p.442).

CMS are a major component of the 'default mode network' (DMN), a brain system containing "a set of interacting brain areas that are tightly functionally connected and distinct from other systems within the brain" (Buckner, Andrews-Hanna & Schacter, 2008, pp.4-5). This network of brain areas was first defined in its characteristics by Gusnard, Raichle and colleagues in a series of articles (Gusnard & Raichle, 2001; Gusnard, Akbudak, Shulman & Raichle, 2001; Raichle et al., 2001). The DMN includes regions along the anterior and posterior midline, the lateral parietal cortex, prefrontal cortex, and the medial temporal lobe. What brought attention to this set of regions was their increased levels of activation during undirected, baseline mental states, as opposed to deactivation in most goal-directed tasks; its discovery was, in fact, entirely accidental (Buckner et al., 2008). The defining feature of the DMN, that is, its increased activity at rest, has proved challenging for defining its function. Buckner and colleagues (2008) have suggested that the DMN might support internal thinking that is detached from the external environment, such as when constructing mental simulations both in the past and in the future, or alternatively, that it might support "exploratory monitoring of the external environment, when focused attention is relaxed" (p.19). Moreover, the anatomy of the DMN can also be informative towards its possible function. For instance, primary sensory or motor areas are not included in the DMN. On the contrary, the DMN includes areas associated with memory (Bucker et al., 2008).

Of particular interest to the present enquiry, self-referential tasks have been found to activate certain components of the DMN, the MPFC in particular (Gusnard et al., 2001). Northoff, Qin and Nakao (2010) found evidence that the DMN's resting-state activity can impact on subsequent stimulus-induced activity in sensory cortices and named this a ‘rest-stimulus interaction’. Qin and Northoff (2011) then hypothesised that self-related stimuli are characterised by a unique rest-stimulus interaction. With the aim of further investigating the relationship between activity in regions involved in self-referential processing, and resting-state activity in the DMN, they carried out a quantitative meta-analysis including 87 fMRI and PET studies. Results showed an overlap between self-referential and resting-state activity in the perigenual anterior cingulate cortex (PACC), which was specifically active during processing of self-related stimuli. Instead, other midline regions part of the DMN, the medial prefrontal cortex (MPFC) and posterior cingulate cortex (PCC), were not characterised by self-specificity, as they also activated during processing of non-self-related, control stimuli.

Qin and Northoff’s (2011) meta-analysis provided further evidence for a ‘rest-self overlap’ in the anterior parts of the DMN (Figure 1.2). Besides this, it also identified the PACC as a region of the cortex which might play a key role in the interaction between self-related activity and resting state activity. The finding of the rest-self overlap led Northoff (2016) to question the tradition to consider the self as a higher-order cognitive function, associated with higher-order cognitive processes such as memory. Self-relatedness has, in fact, been associated with basic cognitive functions, such as perception, action, reward and emotion; moreover, as seen in previous paragraphs, it is associated with the resting state activity of the brain. These findings are a challenge to the characterisation of self as a higher-order cognitive function. Instead, Northoff postulates, “the self may be the most fundamental function of the brain and its intrinsic or spontaneous activity” (2006, p.204).

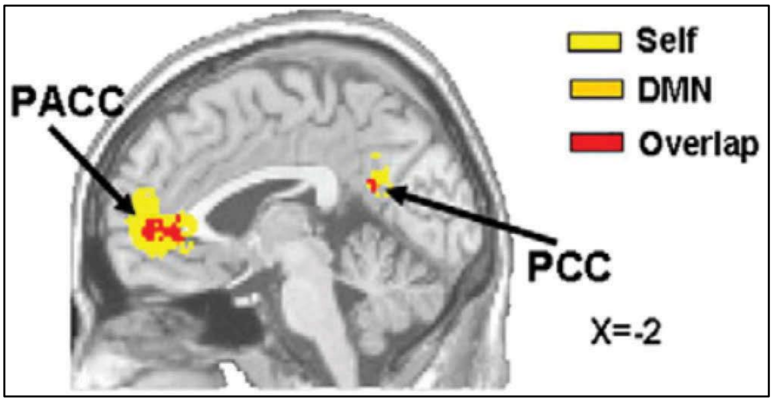

Figure 1.2 Neural overlap between default-mode network (DMN) resting-state activity and self-related processing activity. PACC = perigenual anterior cingulate cortex; PCC = posterior cingulate cortex. Reproduced from Qin and Northoff (2011, p.1229).

1.3.2 Self-Referential Biases on Attention and Memory: A Self-Relevance System?

A striking example of how self-relatedness can be computed pre-attentively is the 'own name effect'. Moray (1959) found that, during a dichotic listening procedure, participants detected their own names when presented in the unattended channel, and also recalled more stimuli in the unattended channel, if presented following their own name, compared with other people's names. The attention-capturing power of one's own name (as of one's own face) suggests a bias for attending to self-related stimuli. One possible explanation for this effect, is that own name representations have a lower threshold for activation. All unattended stimuli might be processed pre-attentively to an extent, however, the lower threshold for one's own name would result in the self-related stimuli attracting attention (Treisman, 1960).

Functional neuroimaging evidence that self-referential processing may be unique, as seen in the previous section, speaks against the hypothesis initially advanced by Klein and Loftus (1988) that the self-reference effect results from the enhanced elaboration and organisation occurring during the processing of self-referenced material, in a way similar to depth-of-processing effects. D. J. Turk, Cunningham and Macrae (2008) hypothesised that, if self-referential processing is indeed functionally distinct from other types of processing, the SRE might be found in conditions where the explicit, evaluative judgement of self-relevant information is not necessary. In order to investigate their hypothesis, they modified the standard trait-evaluation task, to better simulate the undirected contexts in which self interacts with stimuli in the environment. As previous research showed that attention is automatically directed towards self-relevant stimuli such as one's name (Gray, Ambady, Lowenthal & Deldin, 2004) or one's face (Sui, Zhu & Han, 2006), D. J. Turk and colleagues (2008) utilised names and faces to create a context that would activate the self-construct in a non-evaluative, incidental manner. In this implicit task, participants reported whether trait adjectives appeared above or below self-referent and other-referent cues (one's own versus another's name or face). They also included an explicit task involving a standard self-referential trait-adjective paradigm for comparison (e.g., Kelley et al., 2002).

D. J. Turk and colleagues (2008) found that more adjectives presented along with self-reference cues were remembered, compared to other-referent cues, in both explicit and implicit conditions, albeit the magnitude of the memory bias was larger in the explicit encoding condition. Their findings speak against previous claims that explicit elaboration is needed to elicit the self-reference effect (Keenan, Golding & Brown, 2002), as the mere presence of self-cues during the encoding of information proved sufficient to result in a memory enhancement. D. J. Turk and colleagues (2008) offered a potential explanation for the memory enhancement observed, in that self-referred material is characterised by attentional capture. Their findings are also consistent with the argument that self-referential processing is functionally distinct from other-referential processing (Kelley et al., 2002; Northoff et al., 2006).

In wanting to investigate whether self-biases modulate pre-attentive processes, or whether they are dependent on the availability of attentional resources, Humphreys and Sui (2016) reviewed evidence on attentional self-biases and proposed a framework for how self and attention interact, termed the Self-Attention Network (SAN), which includes three main processing nodes: (a) a top-down attentional control network, (b) a self-representation node, and (c) a region involved in bottom-up orienting of attention. According to their model, the nodes interact to determine the brain's response to self-related stimuli; such interactions are both excitatory and inhibitory in nature (as further described in Figure 1.3).

Humphreys and Sui's (2016) model importantly highlights a top-down moderation of bottom-up driven self-related activity. This is important as attentional biases created by high self-relevance can sometimes be disruptive to optimal cognitive functioning, for example, in traumatic experiences (Conway, Pothos & D. J. Turk, 2016). Conversely, there are circumstances in which allocating attention to self-relevant information is beneficial, for instance, to enhance subsequent memory for such information (Conway, 2005). Humphreys and Sui (2016) proposed that the excitatory connections from the top-down attentional control network can elicit self-attentional bias.

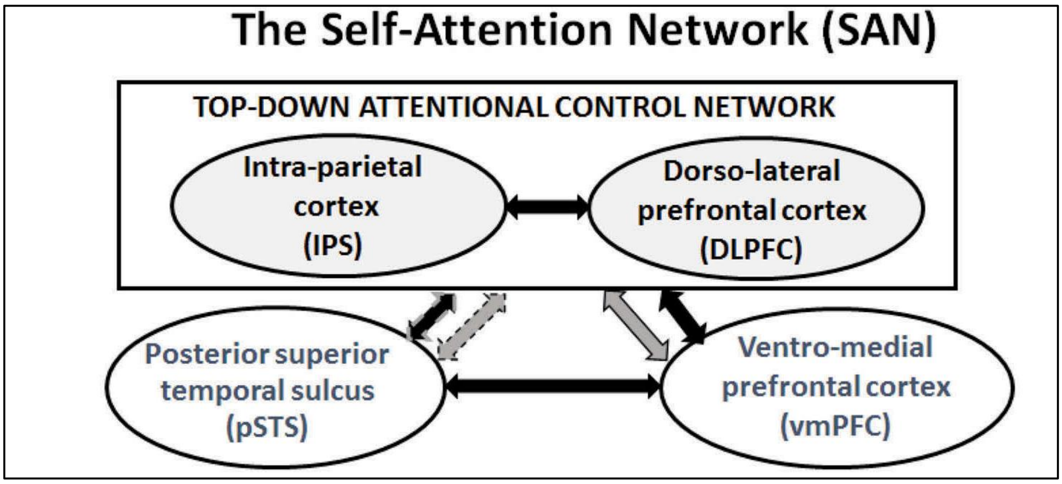

Figure 1.3 The Self-Attention Network (SAN) and its three main processing nodes: (1) a general purpose top-down attentional control network, including the intra-parietal sulcus (IPS) and the dorsolateral prefrontal cortex (DLPFC); (2) a self-representation node, housed in the ventromedial prefrontal cortex (vmPFC); and (3) a region involved in bottom-up orienting of attention, in the posterior superior temporal sulcus (pSTS). Black arrows indicate excitatory connections. Grey arrows indicate inhibitory connections. Dotted arrows highlight connections that need further investigation. Reproduced from Humphreys and Sui (2016, p.12).

In a commentary to Humphreys and Sui's paper, Conway and colleagues (2016) further proposed that the SAN may be "part of a larger self-regulatory system … [termed] the Self-Relevance System (SRS), of which the 'core' or default network is a major part" (p.20). When attention is unfocused, anterior and posterior networks in the DMN are active. These networks also activate whilst remembering the past and imagining the future (Addis, Wong & Schacter, 2007). In other words, when the brain is 'at rest', the outputs of remembering and imagining might be what the SAN attends to. Conway and colleagues (2016) suggested that inhibiting and facilitating such outputs is what shapes attentional biases and behaviour.

In yet another commentary to Humphreys and Sui (2016), Northoff (2016) attempted to further define the underlying neural mechanisms of self-referential processing by advancing a hypothesis for how self-related attentional biases occur. Again, drawing from the evidence of a neural rest-self overlap and rest-stimulus interaction, as seen above, he advanced that "a special form of rest-stimulus interaction [is required] between resting state and self-related stimuli to account for the qualitative and automatic features of self-reference" (Northoff, 2016, p.18).

In an EEG study by Bai and colleagues (2015), pre-stimulus alpha-power was found to predict the degree of self-reference attributed to pictorial stimuli. From this result, taken together with other evidence, Northoff (2016) concluded that the resting state activity has a significant impact on subsequent stimulus-induced activity, and on the extent to which a stimulus is perceived as self-related. Moreover, he argues that this rest-stimulus interaction does not only occur within the CMS as part of the DMN, instead, it may also involve other networks. A "certain degree of self-specificity" (Northoff, 2016, p.19) might be encoded in the balance of the resting state activity of such extended CMS network. It is the degree of such self-specific organisation, according to Northoff (2016), that might define how the resting state reacts to stimuli. A higher degree of self-specific organisation could result into a higher degree of self-specificity attributed to external stimuli, which itself would result into higher automatic self-reference effects, as supported by the SAN advanced by Humphreys and Sui (2016). However, it has to be noted that Northoff's (2016) argument is speculative and needs further investigation.

Although a detailed investigation of the specific neural networks that mediate self-attentional biases is beyond the scope of the present dissertation, a review of these mechanisms is central for an understanding of the operation of self in cognition. In a further commentary, Cunningham (2016) links Humphreys and Sui's SAN to the self-referential memory advantage, by considering its function. Cunningham and colleagues previously argued that ensuring that self-relevant information is not lost is an important ecological function of self-attentional bias (Cunningham, Brady-van den Bos, Gill & D.

J. Turk, 2013). Here she argues that the SAN may serve this function, supporting the self-reference effect. As previously discussed, this memory advantage is observed even when self-association at encoding is incidental (D. J. Turk et al., 2008). Cunningham (2016) further justifies her claim by observing that self-relevance is perpetually pertinent to present goals; thus, the SAN functions to direct attention towards self-cues, and the encoding of information mediated by such attentional bias results in memories which are characteristically episodic in nature, enriched by recollection of detail from the encoding context (Conway & Dewhurst, 1995). Yet, self-relevance can also inhibit the encoding of memory detail, for instance, in traumatic experiences (Conway, Meares & Standart, 2004). In this case, the inhibitory control of self-attentional bias is also critical, as top-down modulation of self-attentional biases may enable the encoding of memory details (Conway et al., 2016).

In conclusion, the SAN framework proposed by Humphreys and Sui (2016), might be able to account for both top-down and bottom-up modulation of self-attentional biases within a larger self-regulatory system as proposed by Conway and colleagues (2016), perhaps serving the ecological function of ensuring that self-relevant information is remembered.

1.4 The Extended Self: Self-Reference through Ownership

> A man's Self is the sum total of all that he CAN call his, not only his body and psychic powers, but his clothes and his house, his wife and children, his ancestors and friends, his reputation and works, his lands, and yacht and bank-account.
>
> (James, 1980, p.291)

The concept of epistemological self initially introduced at the beginning of this chapter can be 'extended' to include, besides one's body and mind, also one's possessions (Belk, 1988). Psychological ownership might offer an alternative way of studying the self and its impact on cognition, through its association with objects. As D. J. Turk and colleagues put it, "object ownership represents the mental synthesis of object and self in time" (D. J. Turk, van Bussel, Waiter & Macrae, 2011, p.3657). Owned objects seem to generally benefit from a special processing status because of their association with self. For instance, objects arbitrarily assigned to oneself are filled with more positive characteristics (the 'mere ownership' effect; Beggan, 1992) and are judged as more economically valuable (the 'endowment' effect; Kahneman, Knetsch & Thaler, 1991), than identical objects that are not assigned to self.

As previously discussed, self-relevant stimuli benefit from an attentional bias that might result in enhanced memory for self-relevant material. Cunningham, Turk, Macdonald and Macrae (2008) therefore predicted that object ownership would impact not only on evaluative processing, but also on the encoding and storage of owned-object representations in memory. They developed a new paradigm to investigate the self-reference effect (Rogers et al., 1977; Symons & Johnson, 1997) through ownership. In the original 'shopping paradigm', participants and a confederate were each assigned a shopping basket, either red or blue, and instructed to imagine they had each won a selection of shopping items available for purchase in a large supermarket (such as food, clothes and electricals). The items were represented by picture cards marked with either a red or blue colour cue. The participants sorted the items in the correct basket, guided by the colour cues. Their memory for the items was later tested with a surprise memory test.

In Cunningham and colleagues' (2008) study, participants remembered more items that were assigned to themselves, than to the confederate participant (with mean proportions of remembered items of .65 and .59 respectively). The ownership effect emerged irrespective of who moved the picture cards into the correct basket. Cunningham and colleagues' (2008) findings thus further extended the SRE beyond the standard trait-rating paradigm, demonstrating that the benefits of self-referential encoding can apply to a wider variety of tasks. Ownership in the shopping paradigm is hypothetical, as participants do not take the objects home. Despite this, this transient ownership context is sufficient to impact on cognition in a significant way, causing a memory advantage for self-owned objects of comparable size to that seen in Turk et al. (2008)..

Cunningham and colleagues (2008) concluded from their findings that association between self and objects through ownership might determine their memorability, in a similar way to the association of trait adjectives to self through implicit self-referential encoding as seen in Turk et al. (2008). . As to how this impact of ownership on cognition arises, they hypothesised that owned objects might preferentially catch visual attention, or trigger direction of attentional resources toward their encoding or retrieval. In addition, reward mechanisms might also play a part in causing the ownership self-reference effect, as acquiring ownership of objects might activate reward circuits in the brain, thus influencing their processing. Neuroimaging studies have explored these hypotheses by investigating the neural basis of the ownership self-reference effect, as discussed in the next section.

1.4.1 The Neural Basis of the Ownership Self-Reference Effect and The Present Enquiry

D. J. Turk and colleagues (D. J. Turk, van Bussel, Brebner et al., 2011; D. J. Turk, van Bussel, Waiter & Macrae) used the shopping paradigm to investigate the contribution of neural systems supporting self-referential processing to the ownership self-reference effect. In a first neuroimaging study participants were scanned using fMRI whilst they completed the shopping paradigm, and their memory for the shopping items was subsequently tested (D. J. Turk, van Bussel, Waiter & Macrae, 2011). Amongst CMS identified by Northoff et al.'s (2006) meta-analysis, ventromedial areas are thought to support the evaluation of stimuli with reference to self, whereas posterior areas, given their connections to the hippocampus, might support the autobiographical self. D. J. Turk and colleagues suggested that, in the case of the trait-rating paradigm (e.g., Kelley et al., 2002), activity in both these areas of the CMS might support the evaluation of stimuli with reference to the self. They hypothesised that in the case of object ownership, as acquiring an object can potentially be a rewarding experience, areas that are associated with reward processing might also be activated.

Indeed, D. J. Turk and colleagues (D. J. Turk, van Bussel, Waiter & Macrae, 2011, p. 3664) identified an "ownership network" of areas in which activity was larger for self-owned than other-owned objects. This network included posterior dorsomedial prefrontal cortex (dMPFC) extending ventrally to caudal anterior cingulate cortex (cACC), anterior inferior parietal cortex, including the supramarginal and postcentral gyri, the left insula, and right superior temporal gyrus. Furthermore, they looked at how activity in the network related to the self-memory bias, and found a positive correlation for some of the areas included in this network. These areas showed temporal patterns of activation by which first, there was activation in dorsomedial superior frontal gyrus (SFG; part of the dMPFC) and cACC, areas known to modulate attention to salient stimuli; then, followed by activity in anterior inferior parietal cortex and insular cortex, implicated in attention for action, and reward signalling, respectively. The areas of the network found to activate for the processing of self-owned objects partially overlapped with CMS, particularly dMPFC and ACC structures (Figure 1.4).

However, some other areas identified in previous studies (e.g., Kelley et al., 2002) as associated with self-referential processing, such as areas within the ventromedial prefrontal cortex (vMPFC) and posterior cingulate, showed larger activity for other-owned objects instead. D. J. Turk and colleagues (D. J. Turk, van Bussel, Waiter & Macrae, 2011) interpreted this controversial finding considering that resting state activity in these areas decreases when required to engage in specified cognitive tasks (Gusnard & Raichle, 2001). These findings showed a potential network of brain regions that support temporary object ownership, besides providing further evidence for the rest-self overlap (Qin & Northoff, 2011).

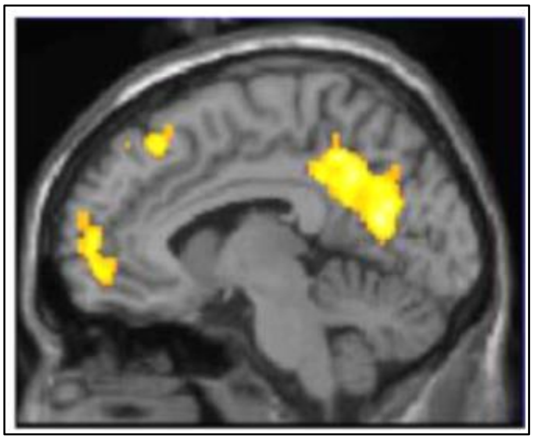

Figure 1.4 Activation of CMS regions during the processing of self-owned objects in D. J. Turk et al. (2011). Highlighted in yellow, areas of CMS which predicted the self-memory bias. Reproduced from D. J. Turk, van Bussel, Waiter & Macrae (2011, p.3663).

As the own-name effect (Moray, 1959) suggests, attention to self-relevant information is automatic. An event-related potential (ERP) study by Gray and colleagues (2004) showed the first evidence that self-relevant words such as one's own name or hometown elicit the P300 component, known as an index of attention. This finding motivated D. J. Turk and colleagues' (D. J. Turk, van Bussel, Brebner et al., 2011) ERP study, in which they investigated attentional biases triggered by object ownership. Specifically, they wanted to determine whether the enhanced attentional processing of self-relevant stimuli, as observed in Gray and colleagues' study, could be initiated online at the time of gaining ownership of an object which one has no personal history with (unlike one's own name or hometown), even if the ownership status is temporary and fictitious. In order to achieve high temporal accuracy in their investigation, they used an ERP version of the shopping paradigm (Cunningham et al., 2008).

D. J. Turk, van Bussel, Brebner and others (2011) found that the P300 component was present for both self-cues and other-cues; however, it was larger for self-cues, suggesting that the attentional bias directed to self-owned stimuli is triggered online at the time of gaining the objects. Furthermore, in a second part of the same study, they also investigated perceptual attention directed to self-owned objects, as measured via the earlier P1 ERP component, known to be associated with sensory-evoked visual activity (e.g., Handy, Soltani & Mangun, 2001). They did so by adapting their paradigm to include a small, task-irrelevant visual distractor to appear before and after the presentation of the ownership cue. Their data showed a decrease in the P1 component for self-owned trials, but only after the ownership cues, to reflect a narrowing of attention to self-owned objects and, therefore, a decrease in sensory-evoked attention capture towards distractors, as denoted by the decreased P1 component.

From these results, D. J. Turk, van Bussel, Brebner and others (2011) concluded that, when one comes into ownership of an object, not only the owned object gets afforded a greater level of higher cognitive processing, but attention also becomes focused on that object at a perceptual level. As the paradigm they used did not include a memory test after the shopping task, it remains unclear how the perceptual and attentional effects they observed might predict the memory bias associated with object ownership previously reported (e.g., Cunningham et al., 2008). With the view of advancing knowledge on how self impacts on cognition overall, the present enquiry aims to investigate self-referential attentional biases, using object ownership to trigger self-reference and, in addition, to also investigate how these biases relate to the self-reference effect in memory.

2 Experiment 1

2.1 Introduction to Experiment 1

2.1.1 Self-referential attentional and memory biases

The attention-grabbing power of our own names (Moray, 1959) suggests a bias for attending to self-relevant stimuli, yet how this self-bias relates to attention needs further defining; specifically, whether self-bias modulates pre-attentive processes, or it depends on attentional resources being available. In Humphreys and Sui's (2016) Self-Attention-Network (SAN), self-bias is characterised both by bottom-up modulation of attention and top-down attentional control. Conway and colleagues (2016) advanced that the SAN may be a sub-system of a Self-Relevance System (SRS), which also comprises the default mode network (for an extended introduction to these models, see 1.3.2).

A bias for attending to self-relevant information in the environment can also be considered in its adaptive function. Cunningham (2016) suggested that the SAN might function to ensure that information that is relevant to the self is attended to and better remembered; attentional biases might support the retrieval of self-relevant information through its preferential encoding. The self-reference effect (SRE), the memory advantage associated with self-relevant information, has been well-documented in the literature (Symons and Johnson, 1997; introduced in 1.2). This is the finding that memory for information encoded in a self-relevant context is enhanced, when compared to information encoded in a non-self-relevant context. This effect is also found when self-reference is incidental and non-directive, such as when to-be-remembered stimuli are presented simultaneously with a self-cue (D. J. Turk et al., 2008).

Another characteristic of the self-memory advantage is that it has been found to be specific to episodic recollection. Tulving (1985) was the first to identify 'remembering' and 'knowing' as ways of differentiating, respectively, the episodic and semantic components of memory, and developed the remember-know (R-K) task. This is a variant of the old-new test memory test, in which participants judge items on whether they have been previously presented in the experiment ('old'), or they are novel ('new'). In the R-K task, after making an 'old' judgement, participants are asked to make a further judgement on whether they 'remember' seeing the item, that is, they recollect specific details of the item's previous presentation, or they simply 'know' that the item was presented before, based on feelings of strong familiarity with the item, without recollecting any specific details.

Using a R-K task, Conway and Dewhurst (1995), found that the memory advantage for self-related stimuli over other-related stimuli was only present for the items which were accompanied by episodic recollection, but not those that were recognised on the basis of familiarity. This finding led Conway and Dewhurst (1995) to suggest that self-referential encoding aids the formation of rich, elaborate representations in memory. Ensuring that information of relevance to self is remembered has been hypothesised as an important ecological function of these self-referential biases (Cunningham et al., 2013). Ultimately, as Cunningham (2016) suggested, defining the relationship between the aforementioned attentional biases and memory is essential for a comprehensive understanding of the self as a cognitive construct.

2.1.2 The role of attention in the ownership self-reference effect

The concept of self can be extended to include one's possessions (Belk, 1988); we are preoccupied with what we own (see 1.4 for an introduction to the ownership self-reference effect). Following Cunningham and colleagues' (2008) findings of the SRE using the shopping paradigm, the ownership self-reference effect was further investigated by van den Bos, Cunningham, Conway and Turk (2010) using a modified version of such paradigm. They wanted to determine whether, in line with Conway and Dewhurst (1995)'s hypothesis that the self-reference advantage is specific to episodic recollection, the effect would only be present amongst recollected items. They included a R-K task after the shopping task and predicted that a memory advantage would still occur for self-owned, compared to other-owned items, yet this advantage would only be limited to recognition judgements accompanied by recollective experience. Indeed, they found that the ownership effect was present only amongst 'remember', but not 'know', responses, suggesting that the memory advantage elicited by ownership is specific to recollection. However, this study employed full-attention conditions, lacking an investigation of the relationship between the availability of attentional resources and such memory advantage.

In order to investigate the role of attention at encoding and its relationship to the subsequent memory advantage, D. J. Turk and colleagues (2013) developed a divided attention (DA) version of the shopping task. Specifically, they wanted to investigate whether the memory advantage that is elicited by ownership depends on the attentional resources recruited by self-ownership cues. The elaboration/organisation account of the SRE (Klein & Loftus, 1988), explains the memory advantage associated with self-reference in light of the enhanced elaboration and organisation of information brought by applying self-knowledge while one is encoding new information. In contrast, D. J. Turk and colleagues (2013) argued that this account is difficult to reconcile with the finding that the self-reference effect is also persistent when self-reference is non-evaluative, that is, when the paradigm used does not require explicit evaluation of information with reference to self-knowledge, such as in the standard trait-adjective paradigm. D. J. Turk and colleagues (2013) hypothesised that such theoretical gap could be overcome by considering the strong "attention capture" (p.504) elicited by self-relevant information, in that items processed as self-relevant, such as a self-owned object, benefit from the automatic recruitment of attentional resources, resulting in elaborate memory representations.

Following the above reasoning, D. J. Turk and colleagues (2013) hypothesised that if the memory advantage for self-owned items is supported by elaborative encoding that is dependent on the availability of attentional resources, then divided attention should reduce or eliminate the ownership self-reference effect. This is because decreasing the availability of attentional resources would result in the selective impairment of self-referential processing of information, resulting in lower memory for self-owned items. Moreover, they also used the R-K task as a memory test, and further hypothesised that the said decrease would only occur for the recollection component of memory. Indeed, they found that self-other differences in recollection were eliminated under divided attention conditions, with a decrease in the proportion of self-owned items recollected, yet this did not occur amongst items recognised based on familiarity.

D. J. Turk and colleagues (2013) concluded that the elaborative self-referential encoding triggered by ownership is attentionally demanding, as the availability of attentional resources proved critical for the self-memory enhancement and, specifically, for the successful retention of episodic detail. As dividing attention did not affect memory for other-owned items, they suggested that elaboration of other-owned items occurs to a lessened extent, even when attentional resources are fully available (D. J. Turk et al., 2013). Their results link well into the model of SAN proposed by Humphreys and Sui (2016), whereby a top-down attentional control mechanism might determine self-referential attentional biases. Indeed, if attentional resources are depleted, this top-down mechanism might not be activated. The results of this study by Turk and colleagues (2013) speak to the important role of attentional mechanisms in supporting self-referential attentional biases in a self-relevance system (SRS; Conway et al., 2016).

Besides behavioural studies, the neural mechanisms underlying self-referential processing have also been investigated (introduced in 1.3). A meta-analysis of brain imaging studies (Northoff et al., 2006) revealed the involvement of a particular set of regions, the cortical midline structures (CMS), when processing stimuli with self-reference. This involvement was observed across domains, leading to the suggestion of self-specificity as a cognitive function supported by the aforementioned structures in the brain, and self-referential processing being central to what the self is (Northoff et al., 2006). Previous studies by D. J. Turk and colleagues investigated the neural mechanisms underpinning the ownership effect with the use of brain imaging techniques (D. J. Turk, van Bussel, Brebner, et al., 2011; D. J. Turk, van Bussel, Waiter & Macrae, 2011; discussed in 1.4.1).

In an fMRI study using the shopping paradigm, D. J. Turk, van Bussel, Waiter and Macrae (2011) identified early activity in the caudal anterior cingulate cortex (cACC), known for modulating attention to salient objects, when processing self-owned items. Their analysis revealed a significant positive relationship between brain activation in this area, and subsequent self-memory bias. In an ERP version of the shopping paradigm, D. J. Turk, van Bussel, Brebner and colleagues (2011) found spatial attention to narrow to the location of self-owned items, as denoted by an increased P1 visual component. Moreover, there was an increase in attentional processing triggered by self-ownership cues, as measured via the P300 component (Polich, 2011). A significant difference in the P300 component was found between ownership conditions, with self-owned items eliciting a larger, more positive P300, than other-owned items (a 'P300 effect'). Previous research has found that P300 indexes attention to self-relevant stimuli (Gray et al., 2004). Both studies by D. J. Turk and colleagues provided further indication that self-referential processing through ownership is dependent upon attentional and perceptual processes.

2.1.3 The present investigation

2.1.3.1 The P300 Effect and Subsequent Memory

ERP-technique provides an excellent covert method of investigation of attention and memory processes; however, the ERP study by D. J. Turk, van Bussel, Brebner and colleagues (2011) did not include a memory test, thus lacking insight into the influence of self-referential attentional bias, indexed by the P300 effect, on later memory performance. A way to investigate this would be to compare ERPs at encoding for items that are subsequently recognised at test ('subsequent hits') and those for items that are not ('subsequent misses'). The differences between these ERPs are termed 'subsequent memory effects' (e.g., Paller & Wagner, 2002). An assumption of this type of ERP studies of memory encoding is that differences observed between neural activity elicited by studied items at encoding, which subsequently attract either correct or incorrect memory judgements, are correlates of processes involved in successful memory formation (Wilding & Ranganath, 2011).

In the particular case of the shopping paradigm, it would be of interest to explore whether a self-other difference in the P300 component, or the 'P300 effect', persisted amongst subsequent hits, but not amongst misses; that is, the P300 effect would persist even amongst items that are subsequently remembered. This would signify that the P300 effect observed is a correlate of encoding processes that contribute to memory qualitatively, beyond only attracting a correct/incorrect memory judgement at test. Perhaps, this contribution could be in the form of amount of information recollected. Following this reasoning, the present research aims, first, to replicate the finding of a P300 effect in D. J. Turk, van Bussel, Brebner and colleagues (2011) with the use of the shopping paradigm. Second, with the addition of a subsequent old-new memory test, it aims to further investigate how the non-evaluative, self-referential encoding achieved through ownership, and the attentional bias that characterises it, are related to the self-memory advantage.

2.1.3.2 ERP Old-New Effects

In addition to the above, by recording ERPs during the old-new test, an investigation of ERP 'old-new effects' will also be carried out in the present study. ERP old-new effects are differences between the neural activity that is elicited by 'old', previously studied items, and 'new', previously unstudied items, that attract correct responses in an old-new test (Wilding & Ranganath, 2011). Old-new effects appear as larger positivities for old compared to new test items. There are two main types of old-new effects which have been the focus of investigation in the ERP literature on recognition memory: 'early' and 'late' old-new effects (for an overview of the contribution of ERPs to the study of memory, see Wilding & Ranganath, 2011). Rugg and colleagues (1998) proposed that the early old-new effect, occurring around 300-500ms post-stimulus, and presenting a mid-frontal scalp topography, is an ERP correlate of familiarity-driven recognition. This effect is also known as the 'FN400 old-new effect', as it comprises the FN400 component. The FN400 component has been found to respond similarly to studied items and similar lures in a number of studies, and has been proposed an index of familiarity-driven recognition (Curran, 2000, 2004). In contrast, the late old-new effect, occurring during a later time window of around 500-800ms post-stimulus, and usually presenting a parietal scalp topography with a left-sided maximum, has been proposed as an ERP correlate of episodic recollection. This effect, also termed the 'left-parietal old-new effect', comprises a late positive component (LPC) peaking at around 600ms post-stimulus. There is a large body of findings supporting that the latter is an index of episodic recollection; moreover, the magnitude of the late old-new effect is known to be sensitive to amount of information retrieved (Vilberg, Moosavi & Rugg, 2006).

Studies using ERPs have also provided evidence for dual-process models of recognition memory (Rugg & Curran, 2007 for a concise review). Such models argue for two distinct memory processes: the one of recollection, which is characterised by the retrieval of qualitative information about the study episode, and the one of familiarity, which provides only a quantitative basis for making recognition judgements (see Yonelinas, 2002, for a review; these models will be discussed in more detail in 3.1.2). Additionally, a further functional distinction between these two memory processes has been proposed, whereby familiarity is a graded index of memory strength, thus will increase with confidence, whereas recollection is a threshold-like process, thus insensitive to confidence manipulations (Woodruff, Hayama & Rugg, 2006).

With the additional recording of ERPs during the test phase of the shopping paradigm, the present study also aims to investigate the ownership modulation of old-new effects and, in particular, of the late old-new effect. If it is true that, as initially hypothesised by Conway and Dewhurst (1995), self-referential encoding specifically enhances episodic recollection, then one would expect to find a modulation of the late old-new effect by ownership, whereby the effect would be larger for self- versus other-owned items.

2.1.3.3 Aims of the present investigation

How does self-reference influence cognition, in particular, how does non-evaluative self-reference at encoding, and its related attentional bias, influence memory at test? In wanting to address these questions, the present experiment:

1. Aims to replicate, by using a computerised version of the shopping paradigm (Cunningham et al., 2008), the finding of a self-reference effect, that is – a memory advantage for self-owned items, compared to other-owned items.
2. Aims to replicate D. J. Turk, van Bussel, Brebner and colleagues' (2011) finding of a P300 effect during the encoding phase of the paradigm, expecting a larger P300 component for self-owned, versus other-owned items.
3. Aims to further investigate how attentional biases during the encoding of self-related information relate to memory performance, by comparing P300 components at encoding, depending on subsequent memory at test.
4. Finally, by also recording ERPs during the memory phase of the paradigm, aims to investigate the ownership modulation of old-new effects, in particular, of the late old-new effect as an index of episodic recollection.

2.2. Method

2.2.1 Participants

Thirty-seven participants (20 female, age: *M* = 24.2 years, *SD* = 4.7 years) were recruited either through the School of Experimental Psychology at the University of Bristol for course credit, or through word-of-mouth for monetary reimbursement. All participants had normal/corrected-to-normal colour vision, with no self-reported history of neurological/psychological disorders, were dominant right-handed and English native speakers.

The study was approved by the University of Bristol Faculty of Science Research Ethics Committee (ID 45654).

2.2.2 Stimuli

The stimulus set comprised of a total of 240 digital images of items sold in major supermarkets, generated from internet search engines. Each image was edited so that each item appeared on a white background, with a black or coloured border (blue/red) and resized to 250 x 250 pixels at a resolution of 149 dpi. The items were divided in three sets of 80, matched on category membership (food, clothes and accessories, household items, electronics) and name length. Assignments of sets to conditions (self, other, new) was counterbalanced across participants following a Latin square design. Stimuli were presented on a cathode-ray tube monitor controlled by a PC using Presentation software (Neurobehavioural Systems, Albany, CA).

2.2.3 Electrophysiological Recording

Scalp potentials were recorded from 32 Ag-AgCl electrodes fitted to a standard electrode layout cap. Electrodes TP9/10 were removed from the cap and used to record from the left and right mastoids. Continuous EEG was sampled at 1000 Hz. Voltages at the scalp were sampled using a BrainAmp DC amplifier (Brain Products GmbH), and were referenced to the FCz electrode. Recordings were initiated with impedances below 10kΩ as measured by ActiCap®. EEG Analysis was performed using BrainVision Analyzer 1.0 (Brain Products GmbH). EEG signal from each electrode was visually inspected and signal from electrodes that showed persistent patterns of noise was interpolated. Ocular correction (Gratton, Coles & Donchin, 1983) was performed using the Fp2 electrode as reference for blink detection (or Fp1, in case Fp2 was interpolated). All electrodes were re-referenced off-line to the average of the left and right mastoid signals and filtered with a bandpass of 0.1-25 Hz, and a notch filter of 50 Hz. Automated artifact rejection was carried out with criteria of a maximum change between adjacent sampling points of 10μV and a maximum change of 200μV across the entire segment. Where more than 10% of trials were rejected on the basis of these artifacts, participants were excluded from the analysis (see 2.3.1). For each remaining participant, EEG data time-locked to the events of interest was epoched into 700ms segments (200 pre- and 500 post-stimulus) for ERPs recorded during the encoding phase, and 1200ms segments (200 pre- and 1000 post-stimulus) for ERPs recorded during the test phase. Baseline correction was performed beginning at 200ms pre-stimulus until stimulus onset. The resulting epochs were then signal-averaged within each condition. These single-subject waveforms were then used to generate grand-averaged waveforms.

2.2.4 Procedure

After filling in the relevant paperwork, and EEG set-up (25-45 minutes), participants were seated in the test room, and given on-screen instructions whilst the experimenter was present to answer any questions on the procedure. The experiment consisted of two tasks. First there was an encoding phase, followed by a memory test. Overall, the total running of the experiment, including the instructions, but excluding EEG set-up, took 45 minutes approximately.

2.2.4.1 Encoding

At the beginning of the experiment, participants were informed they would need to complete two ‘sorting’ tasks during which they would have to sort items in different categories; however, they were unaware their memory for the items encountered during the first task would be later tested in the second task. For the encoding task, participants were informed they would need to undertake a computerised ‘shopping task’. During the on-screen instruction phase, they were assigned a shopping basket (blue or red), and informed that the experimenter was assigned the other basket. During the task, they were presented with shopping items on the screen, one by one, and each of these items was assigned either to them, or the experimenter, by means of a blue/red colour-border appearing around the item, to denote the ownership condition. The participant’s task was to ‘sort’ the items into the correct baskets according to their colour, with a left or right mouse click. Participants were instructed to imagine either they or the experimenter coming into ownership of the items assigned to them. Blue/red ownership conditions were counterbalanced, and the baskets changed left/right positions throughout the task.

Each trial started with a blank screen. After a fixation cross of a variable interval of 2000-2200ms, the current item was presented in the centre of the computer screen, surrounded by a black border. After 400-600ms, the border then changed colour to blue/red (ownership cue). The appearance of the ownership cue denoted the event of interest to which the ERP data was time-locked to (2.2.3). After 800-1000ms, baskets were shown at the top left/right of the screen, for 800-1200ms, during which the behavioural response was made. Baskets changed positions randomly, so that each basket would appear on each side (left/right) for 50% of trials. Participants were instructed to respond using the mouse, with their right hand. Response buttons were spatially aligned with the presented basket images, so that a left click on the mouse would indicate placing the item in the left basket, and vice versa for the right. At encoding, there were two blocks with 80 trials each, resulting in a total of 160 items. Half of items in each block was self-owned, the other half other-owned. Each trial lasted for a total interval of 4000-5000ms (an example trial is illustrated in Figure 2.1). In addition, there was a 50ms blank at the end of each trial, and an inter-trial blank of 1000ms.

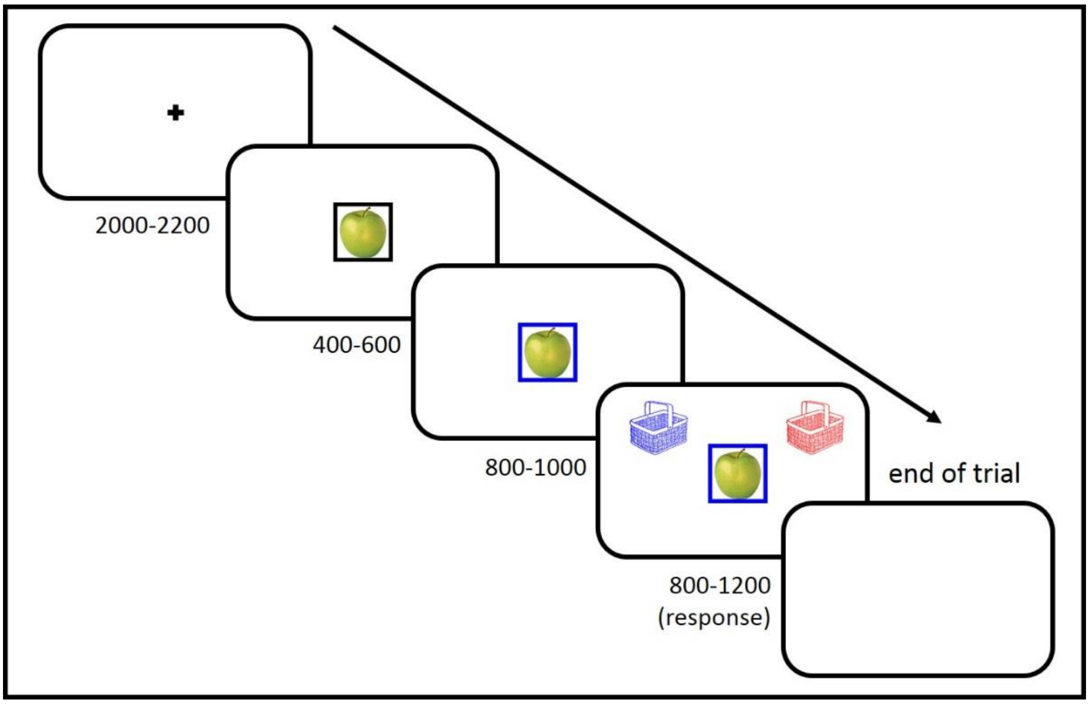

Figure 2.1 Example trial for the encoding task of Experiment 1. All durations are in milliseconds.

2.2.4.2 Test

After a short break, participants were informed on-screen that the second task they needed to complete would be a memory test. They were presented with each of the items they had seen during the encoding task, in addition to novel items they had not previously encountered. The items appeared one by one, black-bordered. The participant's task was to indicate whether they remembered seeing the items before ('old'), or the items were novel ('new'), with a keyboard button press (1 or 3 keys on the number pad). They were invited to "make a guess" in case they could not remember.

After a fixation cross of 2300-2500ms, the current item was presented in the centre of the computer screen, black-bordered, for 600-800ms, at which point behavioural responses started being recorded. The presentation of the black-bordered item was the event of interest to which the ERP data was time-locked to (2.2.3). After the item disappeared, a reminder of which keys to press appeared on the screen for a further 1400-1600ms, giving participants a total response time window of 2000-2400ms. Participants were instructed to respond after the reminder. At test, there were a total of three blocks with 80 trials each, resulting in a total of 240 items. Each trial lasted for a total interval of 4300-4900ms (an example trial is illustrated in Figure 2.2). In addition, there was a 50ms blank at the end of each trial, and an inter-trial blank of 1000ms.

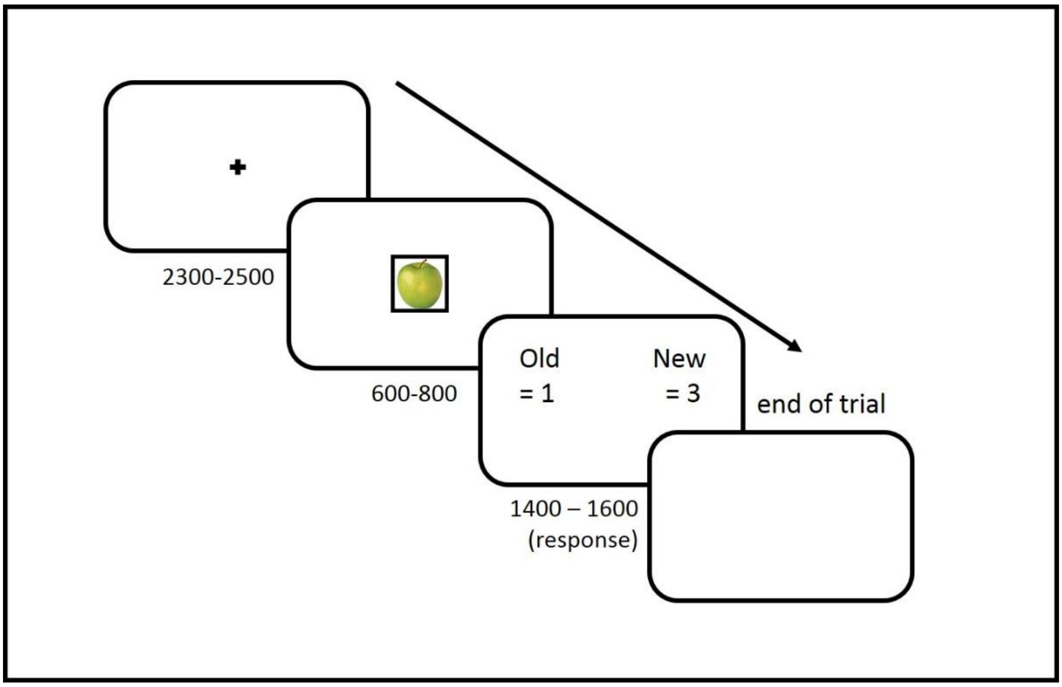

Figure 2.2 Example trial for the memory task of Experiment 1. All durations are in milliseconds.

2.3 Results

2.3.1 Data Processing

Due to technical issues, responses at test were absent for 3 participants. Out of the remaining 34 participants, 2 were excluded as artefact rejection during preliminary data processing exceeded 10% of segments, leaving a sample of 32. Sensitivity index scores (*d'*; Stanislaw & Todorov, 1999) were calculated as a measure of sensitivity to signal against noise. A total of 7 participants were excluded from analysis on the basis of low sensitivity scores (where *d'*< 1; see Appendix A); these participants also scored under 60% overall accuracy, suggesting a low level of engagement with the task (see Figure 2.3). This resulted in a final sample of *n* = 25 for the reported behavioural and electrophysiological analyses, with exception of behavioural analysis of encoding responses; as 2 participants did not make responses at encoding, a sub-sample of *n* = 23 was used for this analysis. However – as their engagement in the memory test was high (total accuracy > 60%), test data from these participants was included in behavioural and ERP analysis.

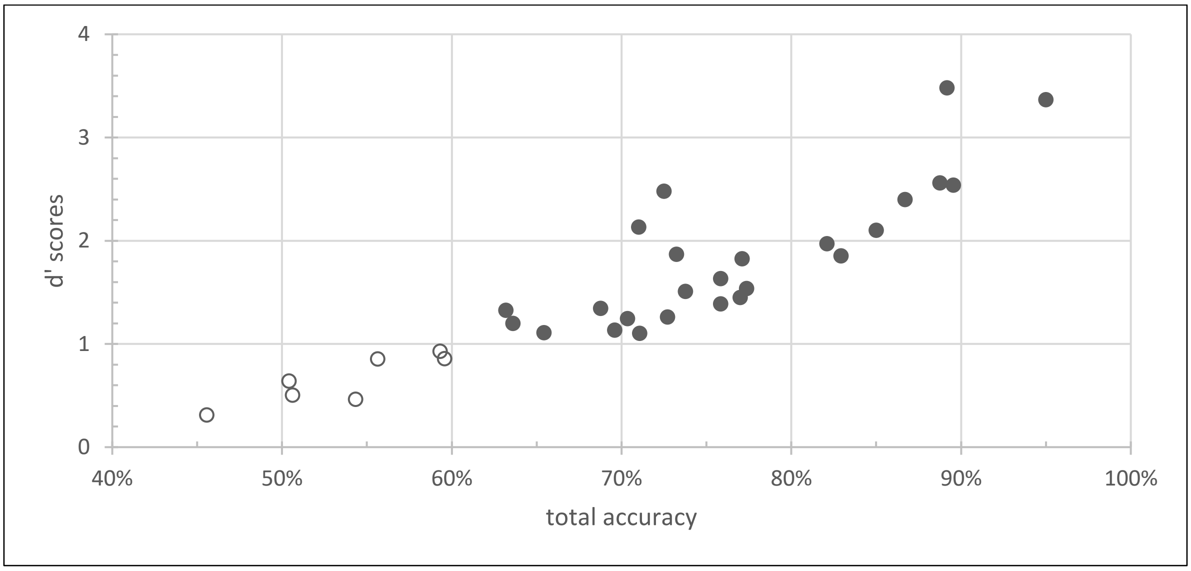

Figure 2.3 Sensitivity index scores (*d'*) over total accuracy for the memory test of Experiment 1. White-filled dots denote participants removed from the analysis due to low sensitivity and engagement (n = 7).

2.3.2 Behavioural Data

2.3.2.1 Encoding

Analysis of response accuracy revealed a small proportion of errors overall (M = .01, SE = .02); accuracy proportions did not differ between ownership conditions, [$t(22) = 0.62$, p =.543], nor did response latencies, [$t(22) = 0.35$, p =.727].

2.3.2.2 Test

Analysis of response accuracy after participant exclusion showed that participants, on average, correctly recognised a mean proportion of .72 (*SE* = .02) old items, with a mean false alarm rate of .14 (*SE* = .02). A paired-samples *t*-test showed that the proportion of self-owned items (*M* = .74, *SE* = .03) recognised was higher than that of other-owned items (*M* = .69, *SE* = .03). This difference, [.05, BCa 95% CI (0.44, 0.87)], was significant, [$t(24) = 2.14$, $p = .043$], and represented a small-to-medium effect size, [$d = .34$]. An ANOVA of median response latencies showed that, for correct responses, participants' response latencies [self: (*EMM* = 1041.99, *SE* = 32.89), other: (*EMM* = 1050.78, *SE* = 31.72), new: (*EMM* = 1075.08, *SE* = 41.82)] did not differ significantly between conditions [$F(1.33, 31.93) = 2.15$, $p = .147$].

2.3.3 Electrophysiological Data

2.3.3.1 Encoding

Following the analysis in D. J. Turk, van Bussel, Brebner and colleagues (2011), a factorial repeated-measures 2x2x3 ANOVA was conducted, with a main factor of ownership (self vs. other), including six total electrodes via sub-factors of scalp location (central: C3, CZ, C4; parietal: P3, PZ, P4) and laterality (left: C3, P3; midline: CZ, PZ; right: C4, P4). Mean amplitude measures were taken at each electrode site over a 100-ms time window centred on the approximate P300 peak time. This time-window was computed using BV Analyzer on the grand-averaged waveform at the PZ electrode. First, P300 peak times between conditions (self: 327ms, other: 334 ms) were averaged, resulting in an averaged P300 peak of 330ms. Then, 50ms were taken at each side of this peak, resulting in a time-window of 280-380ms. This analysis was repeated first on all responses, then on subsequent hit responses only. Mean amplitude measures over the 280-380ms window of interest are reported in Table 2.1 (all responses) and 2.2 (subsequent hit responses). The P300 component of the ERP is shown in Figures 2.4 (all responses) and 2.6 (subsequent hit responses) as a function of ownership condition; the topographies of the respective P300 effects are shown in Figures 2.5 and 2.7.

Table 2.1

Mean amplitudes and self-other differences over the 280-380ms window of the encoding phase of Experiment 1, at selected electrode sites.

	Self		*Other*		*Self – Other*
Electrode	*Mean*	*SE*	*Mean*	*SE*	*Difference*
C3	4.348	.487	3.425	.380	.923
Cz	4.472	.518	3.682	.475	.791
C4	4.577	.427	3.779	.399	.798
P3	1.940	.509	1.001	.442	.939
Pz	2.773	.584	1.869	.549	.904
P4	1.520	.563	0.661	.565	.860

Note. Mean amplitudes in microvolts (μV). SE = Standard Error.

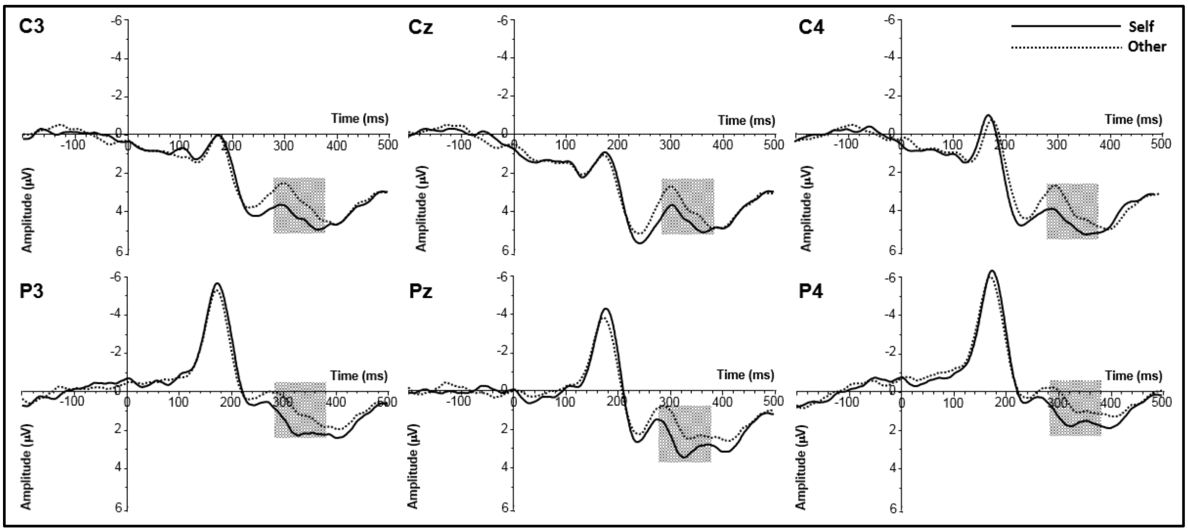

Figure 2.4 ERP grand-averaged waveforms at all electrode sites used in the ANOVA on all encoding responses for Experiment 1, as a function of ownership. The 280-380ms time-window used for analysis is shaded, highlighting the P300 component.

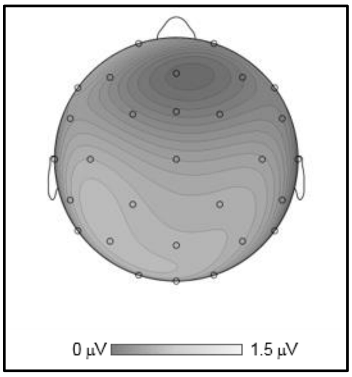

Figure 2.5 Topography of the P300 effect, computed as a subtraction of self – other conditions in the encoding phase of Experiment 1, during the time-window of 280-380ms post-ownership cue.

Table 2.2

Mean amplitudes and self-other differences over the 280-380ms window of the encoding phase of Experiment 1, at selected electrode sites, for subsequent hit responses.

	Self		*Other*		*Self - Other*
Electrode	*Mean*	*SE*	*Mean*	*SE*	*Difference*
C3	4.661	.510	3.457	.413	1.204
Cz	4.757	.527	3.666	.515	1.091
C4	4.853	.478	3.664	.433	1.188
P3	2.304	.532	1.107	.466	1.198
Pz	3.075	.575	1.880	.580	1.195
P4	1.817	.573	.672	.600	1.145

Note. Mean amplitudes in microvolts (μV). SE = Standard Error.

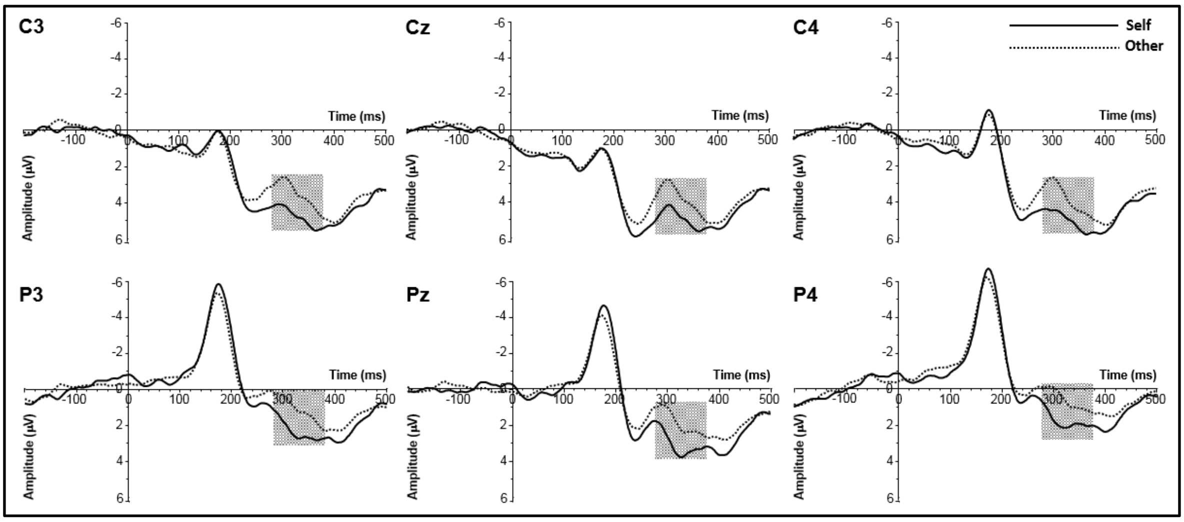

Figure 2.6 ERP grand-averaged waveforms at all electrode sites used in the ANOVA on all encoding subsequent hit responses for Experiment 1, as a function of ownership. The 280-380ms time-window used for analysis is shaded, highlighting the P300 component.

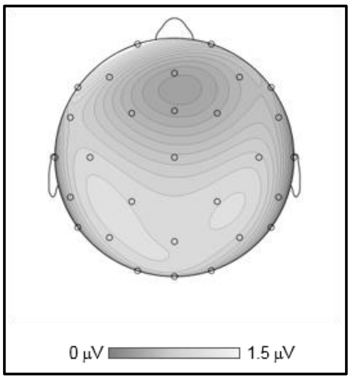

Figure 2.7 Topography of the P300 effect, computed as a subtraction of self – other conditions in the encoding phase of Experiment 1, for subsequent hit responses, during the time-window of 280-380ms post-ownership cue.

2.3.3.1.1 All Responses

Results of the ANOVA for all encoding responses showed a significant main effect of ownership condition [$F(1,24) = 6.966$, $p = .014$, $\eta_p^2 = .225$], such that self-ownership cues elicited a more positive P300 amplitude (*EMM* = 3.27 μV, *SE* = 0.45) than other-ownership cues (*EMM* = 2.40 μV, *SE* = 0.41). This effect did not interact with scalp location [$F(1,24) = 0.109$, $p = .744$], or with laterality [$F(2,48) = 0.512$, $p = .602$].

2.3.3.1.2 Subsequent Memory

Results of the ANOVA on subsequent hit responses only, that is, on ERP responses at encoding for stimuli that were later correctly recognised during the test phase, showed a significant main effect of ownership condition [$F(1,24) = 6.649$, $p = .016$, $\eta_p^2 = .217$], such that self-ownership cues elicited a more positive P300 amplitude (*EMM* = 3.58 μV, *SE* = 0.46) than other-ownership cues (*EMM* = 2.41 μV, *SE* = 0.44). This effect did not interact with scalp location [$F(1,24) = 0.007$, $p = .934$], or with laterality [$F(2,48) = 0.086$, $p = .918$]. Due to a low number of subsequent miss responses, these responses were not included in the ANOVA (see Appendix A).

2.3.3.2 Old-New Memory Effects

Grand-averaged ERP waveforms at test can be seen in Figures 2.8 and 2.9. Mean amplitude measures were taken at each electrode site over the two windows of 300-500ms and 500-800ms, typical, respectively, of early and late old-new effects (Curran, 2004); these are reported in Tables 2.3 and 2.4. Repeated measures ANOVAs werethen conducted at each time window, first on all responses, then on correct responses only (see Appendix A for number of responses). In order to identify the modulation of ownership condition on old-new effects, ANOVAs included a three level main factor of condition (self, other and new), and nine total electrodes via sub-factors of scalp location (frontal: F3, FZ, F4; central: C3, CZ, C4; parietal: P3, PZ, P4) and laterality (left: F3, C3, P3; midline: FZ, CZ, PZ; right: F4, C4, P4); said ANOVAs are reported in the following sections. Where Mauchly's test indicated that the assumption of sphericity was violated, degrees of freedom were corrected using Greenhouse-Geisser estimates. The Bonferroni adjustment was used for all pairwise comparisons.

Table 2.3

Mean amplitude measures taken at the 300-500ms window of ERPs recorded during the test phase of Experiment 1.

Electrode	*Self*	*Self Hits*	*Other*	*Other Hits*	*New*	*Correct Rejections*
F3	-5.39 (4.87)	-5.50 (5.03)	-5.62 (5.02)	-5.96 (4.98)	-6.41 (4.76)	-6.52 (4.77)
FZ	-5.91 (5.34)	-5.93 (5.39)	-6.16 (5.44)	-6.35 (5.42)	-7.31 (5.42)	-7.45 (5.34)
F4	-5.53 (4.93)	-5.53 (4.91)	-5.70 (4.66)	-5.78 (4.80)	-6.97 (4.94)	-7.19 (4.96)
C3	-2.69 (3.95)	-2.71 (3.96)	-2.95 (3.85)	-3.37 (4.01)	-3.58 (3.96)	-3.65 (4.00)
CZ	-3.23 (4.63)	-3.24 (4.54)	-3.69 (4.74)	-3.93 (4.82)	-4.76 (5.18)	-4.90 (5.16)
C4	-2.35 (3.66)	-2.35 (3.68)	-2.85 (3.83)	-3.04 (3.96)	-3.88 (4.26)	-4.10 (4.31)
P3	3.80 (3.89)	3.85 (3.96)	3.38 (3.88)	3.10 (4.36)	2.97 (4.19)	2.89 (4.29)
PZ	3.53 (3.97)	3.57 (4.02)	3.00 (4.08)	2.82 (4.58)	2.30 (4.36)	2.19 (4.48)
P4	4.67 (3.73)	4.65 (3.81)	4.27 (3.66)	4.11 (3.99)	3.59 (4.08)	3.44 (4.12)

Note. Amplitude measures in microvolts (µV) with standard deviations in parentheses.

Table 2.4

Mean amplitude measures taken at the 500-800ms window of ERPs recorded during the test phase of Experiment 1.

Electrode	*Self*	*Self Hits*	*Other*	*Other Hits*	*New*	*Correct Rejections*
F3	- 4.05 (4.47)	-4.07 (4.69)	-4.63 (4.92)	-4.76 (5.12)	-5.16 (4.67)	-5.06 (4.56)
FZ	- 4.42 (4.76)	-4.22 (5.02)	-4.99 (5.06)	-4.96 (5.14)	-6.01 (4.78)	-5.88 (4.50)
F4	- 3.91 (4.60)	-3.63 (4.79)	-4.42 (4.45)	-4.18 (4.48)	-5.96 (4.47)	-5.98 (4.40)
C3	- 0.68 (3.32)	-0.41 (3.47)	-1.26 (3.63)	-1.24 (3.86)	-2.01 (3.48)	-1.78 (3.37)
CZ	- 0.47 (3.45)	-0.03 (3.41)	-1.24 (3.93)	-0.99 (4.03)	-2.40 (4.10)	-2.22 (3.99)
C4	- 0.41 (3.37)	0.06 (3.49)	-1.05 (3.72)	-0.76 (3.72)	-2.27 (3.75)	-2.23 (3.69)
P3	3.91 (3.50)	4.34 (3.64)	3.30 (3.66)	3.58 (4.04)	2.60 (3.80)	2.78 (3.90)
PZ	3.77 (3.60)	4.22 (3.70)	3.16 (4.05)	3.51 (4.36)	2.41 (4.11)	2.61 (4.17)
P4	3.68 (3.09)	4.06 (3.19)	3.12 (3.31)	3.45 (3.50)	2.39 (3.79)	2.56 (3.80)

Note. Amplitude measures in microvolts (µV) with standard deviations in parentheses.

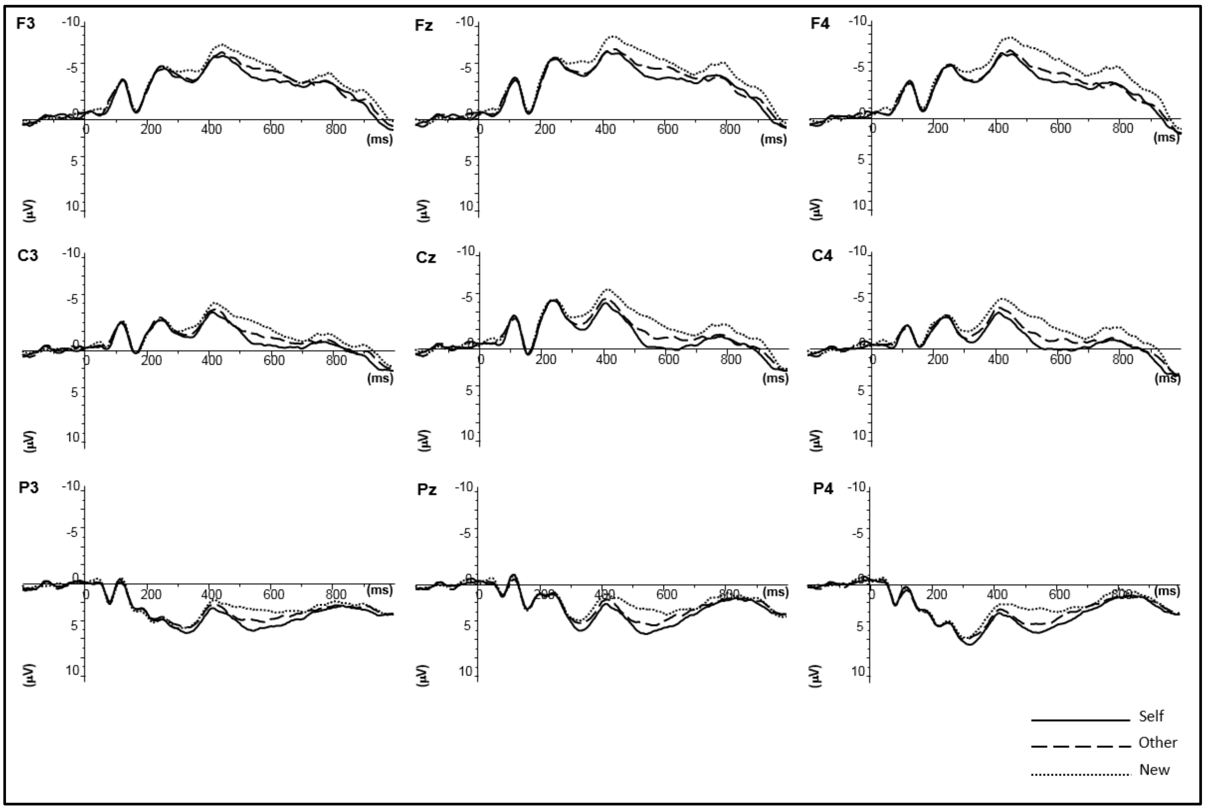

Figure 2.8 ERP grand-averaged waveforms at electrode sites selected for the ANOVA, relative to all responses during the test phase of Experiment 1.

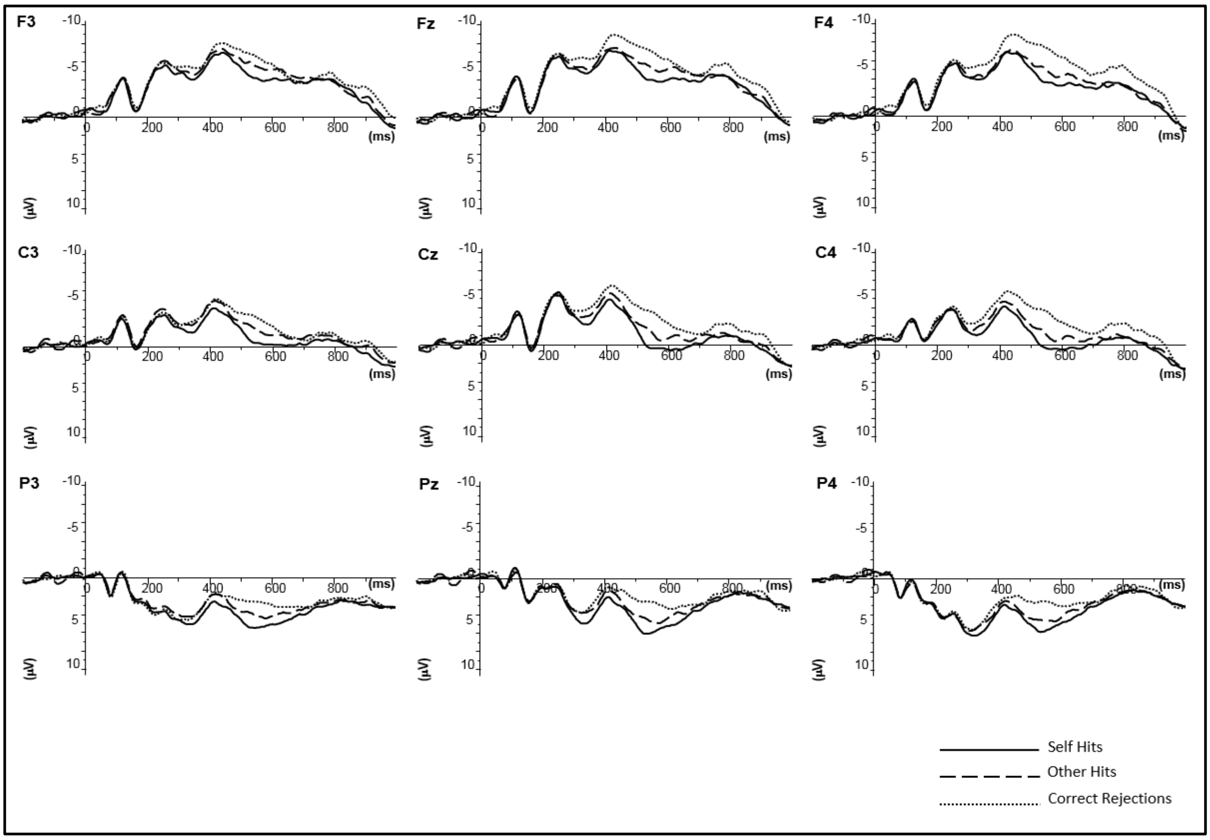

Figure 2.9 ERP grand-averaged waveforms at electrode sites selected for the ANOVA, relative to correct memory judgements, during the test phase of Experiment 1.

2.3.3.2.1 Early Old-New Memory Effect (300-500ms)

Topographies of contrasts in the early window of 300-500ms are shown in Figures 2.10 and 2.11.

2.3.3.2.1.1 All responses

The ANOVA on all responses relative to the 300-500ms window showed a significant main effect of condition, [$F(2,48) = 9.815$, $p < .001$, $\eta_p^2 = .290$]. Average ERP responses to self-owned items (*EMM =* -1.46μV, *SE =* 0.76) were more positive than ERP responses to other-owned items (*EMM =* -1.81μV, *SE =* 0.76*),* which in turn were more positive than ERP responses to new items (*EMM =* -2.67μV, *SE =* 0.81*).* Mean differences between self and new (*MD* = 1.22μV, *p =* .002, *d* = .32) and other and new (*MD* = 0.86μV, *p =* .015, *d* = .22) were significant, yet not between self and other (*MD* = 0.36μV, *p =* .540). An interaction between the main effect of condition and laterality was found, [$F(2.07,49.68) = 3.160$, $\varepsilon = 0.518$, $p = .049$, $\eta_p^2 = .116$]; pairwise comparisons revealed that the means of other and new differed significantly at midline (*MD =* 0.98μV, *p =* .009, *d* = .22) and right (*MD =* 0.94μV, *p =* .005, *d* = .27) sites, but not at left sites (*MD =* 0.61μV, *p =* .122). Mean differences between self and new were significant at all lateralities (left: *MD =* 0.92μV, *p =* .020, *d* = .25; midline: *MD =* 1.39μV, *p =* .001, *d* = .32; right: *MD =* 1.35μV, *p =* .001, *d* = .36). There was no significant three-way interaction.

2.3.3.2.1.2 Correct Responses

The ANOVA on correct responses only (self-hits, other-hits, correct rejections) for the 300-500ms window showed a significant main effect of condition, [$F(2,48) = 9.047$, $p < .001$, $\eta_p^2 = .274$]. Average ERP responses to self-hits (*EMM =* -1.47μV, *SE =* 0.76) were more positive than ERP responses to other-hits (*EMM =* -2.04μV, *SE =* 0.80), which in turn were more positive than ERP responses to correct rejections (*EMM =* -2.81μV, *SE =* 0.81). The mean difference between self-hits and correct rejections (*MD =* 1.35μV, *p =* .001, *d* = .35) and other-hits and correct rejections (*MD =* 0.77μV, *p =* .042, *d* = .19) were significant, yet not between self and other-hits (*MD =* 0.58μV, *p =* .287). An interaction between the main effect of condition and laterality was found, [$F(2.46,59.09) = 5.482$, $\varepsilon = 0.615$, $p = .004$, $\eta_p^2 = .186$]; pairwise comparisons revealed that the means of other-hits and correct rejections differed significantly at midline (*MD =* 0.91μV, *p =* .020, *d* = .20) and right (*MD =* 1.05μV, *p =* .005, *d* = .27) sites, but not at left sites (*MD =* 0.35μV, *p =* .807). Mean differences between self-hits and correct rejections were significant at all lateralities (left: *MD =* 0.97μV, *p =* .017, *d* = .26; midline: *MD =* 1.53μV, *p =* .001, *d* = .36 ; right: *MD =* 1.54μV, *p =* .001, *d* = .41). There was no significant three-way interaction.

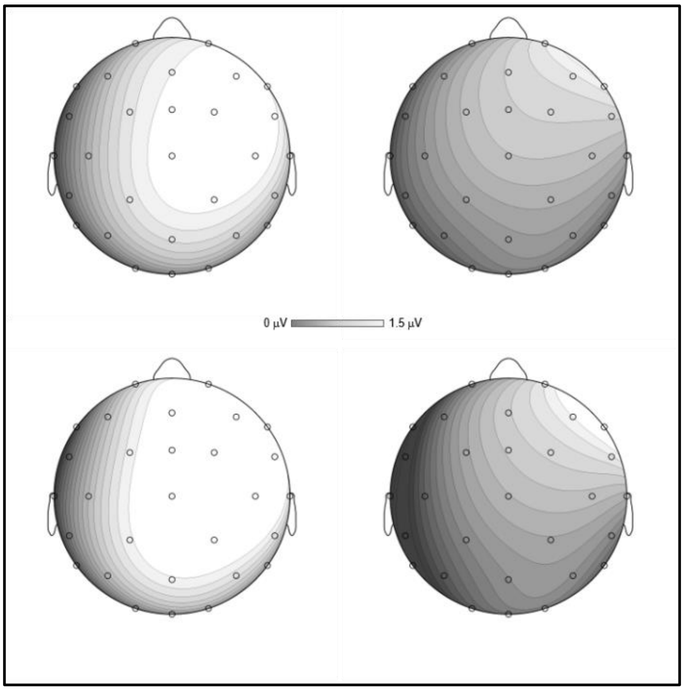

Figure 2.10 Topography of old-new contrasts in ERP waveforms at the 300-500ms time-window of the test phase of Experiment 1. Top left: self – new (all responses); top right: other – new (all responses); bottom left: self-hits – correct rejections; bottom right: other-hits – correct rejections.

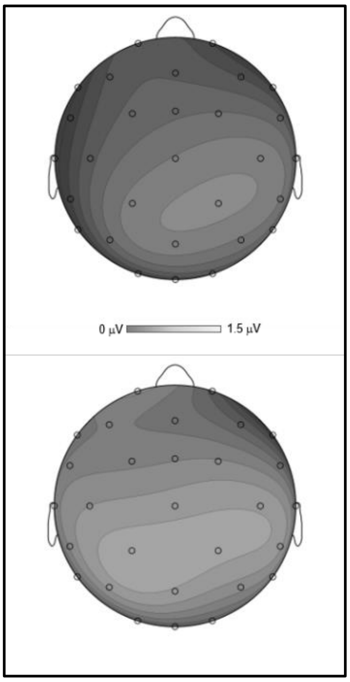

Figure 2.11 Topography of self-other contrasts in the ERP waveforms at the 300-500ms time-window of the test phase of Experiment 1. Top: self – other (all responses); bottom: self hits – other hits.

2.3.3.2.2 Late Old-New Memory Effect (500-800ms)

Topographies of contrasts in the late window of 500-800ms are shown in Figures 2.12 and 2.13.

2.3.3.2.2.1 All Responses

The ANOVA revealed a significant main effect of condition, [$F(1.54, 36.92) = 8.728$, $\varepsilon = .769$, $p = .002$, $\eta_p^2 = .267$]. Average ERP responses to self-owned items (*EMM* = -0.29μV, *SE* = 0.65) were more positive than ERP responses to other-owned items (*EMM* = -0.89μV, *SE* = 0.71), which in turn were more positive than ERP responses to new items (*EMM* = -1.82μV, *SE* = 0.73). Pairwise comparisons revealed a significant difference between the means of self and new (*MD =* 1.535μV, *p =* .001, *d* = .45); mean differences between other and new (*MD =* 0.933μV, *p =* .146) and self and other (*MD =* 0.602μV, *p =* .102) were not significant.

A significant interaction between the main effect of condition and laterality was found, [$F(2.68, 64.30) = 3.152$, $\varepsilon = .670$, $p = .036$, $\eta_p^2 = .116$]. Pairwise comparisons showed that the mean difference of self and new was significant at all lateralities, albeit with different significance levels (left: *MD =* 1.25μV, *p* = .005, *d* = .37; midline: *MD =* 1.63μV, *p* = .001, *d* = .45; right: *MD =* 1.73μV, *p* = .001, *d* = .51). Although there were no other significant mean differences to emerge in these comparisons, the mean difference of other and new approached significance at the $p < .05$ level at right sites (*MD =* 1.17μV, *p* = .056, *d* = .33).

A significant 3-way interaction between the main effect of condition and location and laterality was found, [$F(8,192) = 3.760$, $p < .001$, $\eta_p^2 = .135$). Mean differences between self and new were significant at all lateralities for all sites, with the mean difference at left frontal sites being the smallest (*MD* = 1.11μV, *p* = .040, *d* = .25) and the mean difference at right frontal sites being the largest (*MD* = 2.05μV, *p* <.001, *d* = .46). The mean difference of other and new was significant at right, frontal sites (*MD* = 1.54μV, *p* = .004, *d* = .35).

2.3.3.2.2.2 Correct Responses

A second repeated measures ANOVA was then conducted for correct responses only (self-hits, other-hits and correct rejections). There was a significant main effect of condition, [$F(2,48) = 8.010$, $p = .001$, $\eta_p^2 = .250$]. Average ERP responses to self-hits (*EMM* = 0.04μV, *SE* = 0.68) were more positive than ERP responses to other-hits (*EMM* = -0.71μV, *SE* = 0.74), which in turn were more positive than correct rejections (*EMM* = -1.69μV, *SE* = 0.71). Pairwise comparisons revealed a significant mean difference between self-hits and correct rejections (*MD =* 1.72μV, *p* = .001, *d* = .51); whereas mean differences between other-hits and correct rejections (*MD* = 0.98μV, *p* = .201), and self and other-hits (*MD* = 0.74μV, *p* =.165) did not reach significance.

A significant interaction between the main effect of condition and laterality was found, [$F(2.68, 64.42) = 5.171$, $\varepsilon = .671$, $p = .004$, $\eta_p^2 = .177$]. Pairwise comparisons showed that the mean difference between self-hits and correct rejections was significant at all lateralities (left: *MD* = 1.31μV, *p* = .015, *d* = .38; midline: *MD* = 1.82μV, *p* = .001, *d* = .51; right: *MD* = 2.05μV, *p* < .001, *d* = .60). A significant mean difference between other-hits and correct rejections also emerged at right sites (*MD* = 1.39μV, *p* = .034, *d* = .40).

A significant 3-way interaction between the main effect of condition and location and laterality was found, [$F(8,192) = 6.754$, $p < .001$, $\eta_p^2 = 0.220$]. The mean difference between self-hits and correct rejections was significant at all lateralities for central (left: *MD* = 1.37μV, *p* = .011, *d* = .41; midline: *MD* = 2.18μV, *p* <.001, *d* = .60; right: *MD* = 2.28μV, *p* <.001, *d* = .65) and parietal (left: *MD* = 1.56μV, *p* = .004, *d* = .42; midline: *MD* = 1.60μV, *p* = .004, *d* = .42; right: *MD* = 1.51μV, *p* = .008, *d* = .44) sites, but only at midline (*MD* = 1.66μV, *p* = .012, *d* = .36) and right (*MD* = 2.36μV, *p* <.001, *d* = .52) lateralities for frontal sites. The mean difference between other-hits and correct rejections was significant at right frontal (*MD* = 1.81μV, *p* = .003, *d* = .42) and right central (*MD* = 1.47μV, *p* = .042, *d* = .40) sites.

2.3.4 Results Summary

In summary, analysis of test behavioural data revealed that participants recognised a significantly higher number of items assigned to self than to other (2.3.2.2). Analysis of encoding ERPs revealed a P300 effect, whereby the self-ownership cues elicited a larger P300 than other-ownership cues; the P300 effect was present also amongst subsequently recognised items (2.3.3.1). With regards to memory ERPs (2.3.3.2), an old-new effect was found, onsetting at 300ms, whereby correctly recognised old items elicited more positive ERPs than correctly rejected new items (Figure 2.9). Of interest to the present enquiry, there was a modulation of ownership on the late parietal old-new effect, whereby self-hits elicited more positive ERPs than other-hits, in the 500-800ms window. Although this difference was apparent in the ERP waveforms, it was not statistically significant (2.3.3.2.2.). Such ownership modulation was not apparent in the early mid-frontal old-new effect.

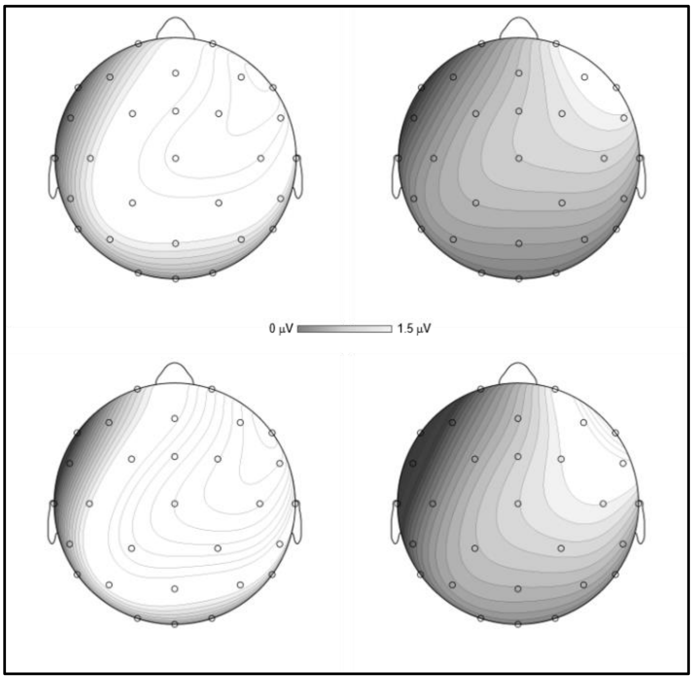

Figure 2.12 Topography of old-new contrasts in the ERP waveforms at the 500-800ms time-window of the test phase of Experiment 1. Top left: self – new (all responses); top right: other – new (all responses); bottom left: self-hits – correct rejections; bottom right: other-hits – correct rejections.

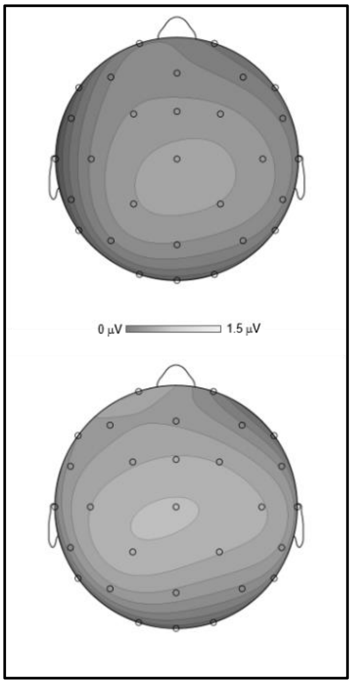

Figure 2.13 Topography of self-other contrasts in the ERP waveforms at the 500-800ms time-window of the test phase of Experiment 1. Top: self – other (all responses); bottom: self hits – other hits.

2.4 Discussion

2.4.1 P300 Effect and Subsequent Memory

In the present experiment, during the encoding phase participants sorted pictures of objects as either belonging to themselves, or the experimenter, based on a colour cue, whilst ERPs were being recorded. A purpose of this experiment was to compare the P300 components elicited by self and other ownership cues at encoding. A P300 component is elicited by the engagement of higher-order cognitive processes associated with selective attention and resource allocation (Donchin & Coles, 1988). Specifically, it has been suggested to index neural inhibitory activity that enhances attentional focus to promote memory storage (Polich, 2011). ERP responses to self-ownership cues elicited a P300 component that was larger in amplitude, when compared to other-ownership cues. This difference, referred to as 'P300 effect', was statistically significant, suggesting increased attentional processing for self-relevant stimuli.

As well as replicating D. J. Turk and colleagues' findings (2011), the finding of a P300 effect fits in within the larger framework of research on attentional biases towards self-relevant stimuli, described previously in this chapter (2.1.1). According to previous work by Gray and colleagues (2004), self-relevant stimuli receive preferential access to attentional resources, as indicated by the P300 effect, when compared to other, non-self-relevant stimuli. It is important to stress that, in the present experiment, as in D. J. Turk and colleagues' experiment (2011), participants were aware that ownership of items would be temporary and fictitious, yet this was sufficient for the attentional benefits toward self-owned stimuli to manifest.

With the aim to investigate the relationship between the P300 effect elicited by ownership and the self-memory bias observed in other behavioural studies using the shopping paradigm (Cunningham et al., 2008; van den Bos et al., 2010), the present experiment also included a memory test, with the intention to contrast ERP responses at encoding depending on subsequent memory. In the test phase of the study, participants were presented with the items already seen in the encoding task in addition to novel items, and their task was to indicate whether they remembered seeing the items ('old'), or the items were novel ('new'). Analysis of responses in the old-new memory test revealed a self-reference effect (SRE; Symons & Johnson, 1997), with a memory advantage for self-owned versus other-owned items, whereby more items assigned to self were remembered than items assigned to other. The effect size was consistent with that reported in Symons and Johnson's (1997) meta-analytical review of the literature.

In the present data, the number of misses epochs was low, being less than 20 for a few participants, after participant exclusion (see Appendix A). In order to compute any reliable grand-averaged ERP waveforms for study items that were subsequently forgotten, within each of the two ownership conditions, the number of epochs would need to be at least 30 for each condition to be included in a comparison (Luck, 2014). For this reason, it was not possible to include subsequently forgotten items in the analysis. It is a common challenge of ERP studies of memory to reach a level of performance that is high enough to suggest that participants are sufficiently engaged with the task, whilst also obtaining enough mistake trials contributing to all conditions of interest (Rugg & Coles, 1995).

Despite the above limitation, it was still possible to investigate self-other differences amongst subsequently recognised items, as planned. Results revealed a P300 effect persisted amongst subsequent hits, suggesting that the difference in neural activity seen at encoding of self- and other-owned items does not only reflect that a larger number of self-owned items, compared to other-owned items, was classified as old at test. In other words, the persistence of the effect amongst subsequent hit responses suggests that the self-attentional bias indexed by the P300 might be contributing to qualitative aspects of subsequent memory, which were not measured by the old-new test used in the present study. Indeed, in the present data, the modulation of the P300 component by ownership is not accounted for by the differentiation of encoding responses according to subsequent old-new memory judgements alone.

In other ERP studies, subsequent memory effects have been found between study items that, at time of test, were recognised with the additional recovery of context information, and items recognised with sufficient information only to make an accurate recognition judgement. Results of these studies are mixed, and further work is needed to determine if and how ERPs are sensitive to encoding processes that predict whether contextual information of the study episode will be recovered during test (for a review, see Wilding & Ranganath, 2011). As the present study did not investigate whether contextual information was also recovered, when an item was recognised, it can not be related to this literature. Further research could investigate the attentional mechanisms of self-referential encoding using the ownership paradigm, by relating the P300 at encoding to the retrieval of contextual information.

2.4.2 Ownership Modulation of Old-New Effects

As part of the present experiment, ERP responses were also recorded during the test phase, in order to explore if and how ownership modulated old-new memory effects – in particular, the late parietal old-new effect. Discussion of results of old-new effects analyses will focus on correct responses, as per definition, old-new memory effects are “differences between the neural activity that is elicited by old (previously studied) and new (previously unstudied) items that attract correct task [old-new] judgments” (Wilding & Ranganath, 2011; p. 378). The pattern of an old-new effect was found, onsetting at 300ms post-stimulus, whereby ERP responses for old items were more positive, overall, than for new items (Figures 2.8 and 2.9). This difference should not have been affected by behavioural response activity as instructions to respond appeared separately to, and after, the item (Figure 2.2).

2.4.2.1 Early Old-New Effect

A negative peak occurred around 400ms; this peak was of a greater (negative) amplitude for responses to new items than both self and other responses. With regards to the topography of this early old-new effect, when considering the contrast of other-new responses, the effect showed a clearer right frontal topography, than for the self-new contrast, where the effect maximum shifted towards more mid-central locations. Analysis of self-other contrasts revealed that a larger positivity arose for self-owned items when compared to other-owned, which presented a parietal maximum in its topography, albeit without constituting a significant effect (Figures 2.10 and 2.11).

The old-new pattern described above is congruent with that of a FN400, with a frontal negative-going peak of a 400ms latency. There were no evident differences between self and other in the FN400 component, thus suggesting that ownership condition did not have any significant modulation on this early, frontal effect. In the present study, the number of false alarms was too low to include them as a condition in any of the ERP analyses (see: Appendix A), meaning they could not be used for comparison to hit responses. As the FN400 component has been proposed as an index of familiarity-driven recognition (Rugg & Curran, 2007), this result can be interpreted as ERP evidence that self-referential encoding through ownership does not enhance familiarity-based recognition, as already found in behavioural studies (van den Bos et al., 2010; D. J. Turk et al., 2013).

2.4.2.2 Late Old-New Effect

Of particular interest to the present research is the influence of self-reference on memory retrieval, as measured by ERPs, as a novel aspect introduced in this experiment. As self-referential encoding has been proposed to enhance the recollection component of memory (Conway & Dewhurst, 1995), a modulation of the late parietal old-new effect by ownership was hypothesised to reflect this enhancement, as this ERP effect is known to be related to recollection (Rugg & Curran, 2007). The data showed a late old-new effect onsetting around 400-500ms post-stimulus, whereby responses to items correctly recognised as old (hits) were more positive-going than responses to items correctly classified as new (correct rejections). Specifically, the waveform pattern was consistent with the above hypothesis, with responses to self-owned hits being more positive than other-owned hits, although this difference was non-statistically significant. However, it has to be noted that, due to the presentation variance in item duration times (600-800ms; see Figure 2.2), response-related activity for some items will have begun whilst ERPs for the late window of interest (500-800ms) were still being recorded. This would have created noise in a considerable portion of this window (600-800ms). Although this limitation needs to be taken into account in interpreting these results, the late positive component peaked before the 600ms mark (Figures 2.8 and 2.9), therefore the ownership modulation of the late old-new effect is still apparent in the data, given its earlier onset.

The self-other differences observed in these ERP contrasts are not attributable to targetness, as items in both conditions required the same type of response ('old'). The magnitude of the late old-new effect is known to be sensitive to amount of information retrieved (Vilberg et al., 2006). It was evident from the inspection of waveforms, that ownership modulated the late old-new effect, even if to a non-statistically significant extent. A possible interpretation is that this modulation might reflect a larger amount of information retrieved about self-owned items. However, as the amount of information retrieved about recognised items was not measured in the present paradigm, this interpretation is speculative.

The topography of self-other contrasts presented a mid-central maximum (Figure 2.13). In ERP studies of memory, the typical parietal topography of the late old-new effect is observed when comparing ERPs associated with correct memory judgements which are accompanied by recollection of the previous occurrence of the item, to those that are not. Such comparison usually results in a larger effect for items accompanied by recollection, as opposed to those only recognised based on familiarity (Rugg & Curran, 2007). Self-reference, besides resulting in a larger number of successfully retrieved items, as consistently found in studies investigating the SRE (Symons & Johnson, 1997), has also been argued to enhance recollection of items specifically, and behavioural evidence for this claim has been found by using the shopping paradigm (van den Bos et al., 2010; D. J. Turk et al., 2013).

According to the above reasoning, self-other contrasts in the present ERP data would be expected to isolate the recollection component to an extent, in that recognition of self-owned items would be supported by the involvement of brain regions and processes specific to recollection, to a greater extent than other-owned items. However, it is important to stress that, to isolate the ERP component associated with the process of recollection, an experimental paradigm containing a test such as a remember-know task is needed, whereby one can compare responses that are supported by recollection to familiarity-based responses. In the present paradigm, a proportion of self-owned items might have been recognised on the basis of familiarity only, and equally, some recognised other-owned items might have been accompanied by recollection. Thus, comparing self- to other-hits cannot isolate the recollection component, even though self-hits are expected to be accompanied by recollection to a greater extent than other-hits. As the present experiment did not make use of a test such as the R-K task, the above interpretation of observed self-other differences in the late old-new effect is made with caution and needs further investigation. Future ERP studies that aim to investigate how self-reference modulates the late old-new memory effect could employ paradigms that allow an experimental dissociation of the processes of recollection and familiarity.

In addition to the above interpretation, self-other differences observed in the ERP waveform might also reflect the involvement of self-specific brain structures (Northoff et al., 2006). Future studies could aim to investigate whether the self-other differences observed during memory retrieval are qualitative rather than quantitative in nature; specifically, whether (a) they can be attributed to the activity in self-specific brain structures involved in the retrieval of self-related stimuli, or (b) they can be attributed to differences in the level of activity in the same structures involved in retrieval of other-related stimuli. Importantly, these possibilities are not mutually exclusive; another possibility is that (c) the self-other differences seen in the present study might be supported by brain regions that are both involved in self-specific processing, and memory retrieval. As described concisely by Rugg and Coles (1995): "differing ERP scalp distributions provide a necessary but not a sufficient condition for the conclusion that functionally distinct processes have been identified" (p.34). Given the limitations posed by using ERP-technique, future studies could employ other imaging techniques which allow one to make firmer conclusions about the functional distinction of processes of interest, in this case, whether self-specific brain structures support the processes that elicited the observable self-other differences in the present ERP enquiry.

3 Experiment 2

3.1 Introduction to Experiment 2

3.1.1 Experiment 1 findings

In Experiment 1 event-related potentials (ERPs) were recorded whilst participants completed a shopping paradigm and a subsequent old-new memory test. A self-reference effect (SRE; Symons & Johnson, 1997) was found, with a memory bias for items encoded within a self-ownership context. More self-owned items were remembered than other-owned items. On the basis of the hypothesis that self-referential encoding enhances recollection specifically (Conway & Dewhurst, 1995), the ERP data from the test phase of Experiment 1 was hypothesised to show an ownership modulation of the late-parietal old-new effect, well-characterised in the literature as an index of recollection, (Rugg & Curran, 2007), to reflect the expectation that recognition of self-owned items would be accompanied by recollection to a greater extent than that of other-owned items.

Results of Experiment 1 revealed a modulation of the late old-new effect by ownership, with self-hits eliciting larger positivities than other-hits, when compared to correct rejections. However, self-other differences were not statistically significant. It was argued that a proportion of self-owned items classified as ‘old’ in the old-new test used might have been recognised on the basis of familiarity processes only, and thus comparing self-other hit responses could not isolate the recollection component of memory, even though self-hit responses might have been accompanied by recollection to a greater extent than other-hit responses. As the old-new test used in the paradigm did not provide an experimental dissociation of the processes of recollection and familiarity, a further investigation of the ownership modulation was proposed, that uses a different memory test, to investigate the mechanisms eliciting the self-other differences observed (see 2.4 for discussion of Experiment 1 findings).

3.1.2 Dual-process models of recognition memory

A prominent account of recognition memory, dual-process models distinguish between the two processes of recollection and familiarity (for a review, see Yonelinas, 2002). The distinction between the two is illustrated by the common experience of recognising someone as familiar (knowing) without being able to recollect who they are, or where one has previously encountered them (remembering). It has previously been found that, when recognition is accompanied by recollective experience, participants have a strong feeling of the self-reference of the remembered event (Conway & Dewhurst, 1995). Conway and Dewhurst offered a potential explanation for this in that “recollective experience necessarily entails a rememberer (self) who is remembering” (1995, *p. 2*).

Instead, when one's memory for a fact, or a person, is only accompanied by feelings of familiarity, lacking recollective experience, self-reference is not necessarily entailed in remembering.

According to several dual-process models, recognition memory judgements are supported by these two distinguished processes. These models (e.g., Atkinson & Juola, 1973, 1974; Jacoby, 1991; Mandler, 1979; Tulving, 1985; Yonelinas, 1994) agree about some defining characteristics of recollection and familiarity, as reviewed by Yonelinas (2002). First, familiarity is quicker than recollection and is supported by brain regions that are earlier in the processing stream. Moreover, recollection and familiarity are independent during retrieval, however their relationship during encoding is less clear. Furthermore, some models describe familiarity using signal detection theory, whereby the familiarity signal for old items exceeds that of new items, but their distributions overlap, whilst recollection has been described as a threshold process (Yonelinas, 2002).

Vilberg and Rugg (2008) conducted a meta-analytical review of event-related fMRI studies on the loci of 'retrieval effects' (the fMRI equivalent of ERP old-new effects) elicited by familiarity- and recollection-related recognition judgements. In particular, they were interested in the modulation of activity in the parietal cortex by type of judgement. Results of their meta-analysis showed that familiarity and recollection-related retrieval effects were localised to different areas of the lateral parietal cortex. More specifically, familiarity-related effects were localised around the intra-parietal sulcus (IPS), whereas recollection-related effects were localised to the posterior part of the inferior parietal cortex.

From their findings of the above dissociation, Vilberg and Rugg (2008) concluded that retrieval-related effects cannot be explained by a single memory process, thus providing more evidence for dual-process models of recognition memory. Furthermore, they also suggested that the retrieval-related activity in inferior parietal cortex indicates specificity of this region in recollection. On the contrary, activity observed in superior parietal cortex (including the IPS), indexes activity related to successful retrieval yet without the implication of specificity of this region in familiarity-based recognition.

3.1.2.1 The R-K task

A functional dissociation of the two processes of recollection and familiarity cannot be inferred from old-new tests which do not include a manipulation distinguishing between the two (Gardiner, 2008). In order to determine the effect that self-reference has on underlying memory processes, specifically, on the memory processes that correspond to the experience of episodic recollection, an experimental paradigm needs to aim to isolate such memory process(es) – even though no experimental manipulation can be process-pure. At present, amongst the paradigms that best serve this purpose is the 'remember-know' task (R-K task), initially developed by Tulving (1985).

In the remember-know (R-K) task, participants are first asked whether they remember seeing an item before ('yes' or 'no'), in a similar way to an old-new test. When a 'yes' response is given, the participant is then asked to judge whether they recollect something they consciously experienced at the time of seeing the item at first, that is, they have an episodic recollection of seeing the item ('remember'), or whether the item seems familiar in that they feel confident they have seen it before, however they do not recollect anything else they experienced when they saw it at first ('know'). Further to the initial R-K task, an option of 'guess' response is also included in Gardiner and Richardson-Klavehn's (2000) version of the task, so to remove a potential confounding for recognition decisions that are not associated neither with experiences of remembering nor with knowing, instead with strategically based decisions, or mere mistakes.

Although the use of the R-K task to estimate the contribution of recollection and familiarity-based recognition to memory has been disagreed upon, in his review Yonelinas (2002) concluded that the R-K task is comparable to other tasks used to dissociate recollection and familiarity, for instance, the 'process-dissociation' procedure, first developed by Jacoby (1991). In this procedure, participants study two lists of items, one presented visually, and one auditorily. Recollection is then measured as memory for the study context. A potential limitation of this procedure is that it does not account for partial recollection, that is, the recollection of information that does not contribute towards the distinction of seen/heard. In contrast, as the R-K procedure measures recollection based on subjective reports, it accounts for partial recollection. Also, in favour of Yonelinas's argument that the R-K task is a valid experimental dissociation of the two processes, 'remember' and 'know' responses typically present different ERP and fMRI correlates (Rugg & Curran, 2007; Vilberg & Rugg, 2008).

3.1.3 The Self-Reference Recollection Effect (SRRE)

The above distinction between remembering and knowing can be useful to investigate the impact of self in recognition memory, in that encoding manipulations that trigger self-reference, such as the shopping paradigm, should enhance recollective experience. Information encoded through self-reference benefits from the elaborative nature of the self-construct (Symons & Johnson, 1997). Self-referential manipulations can aid the formation of subjective, episodic representations of the original event which are rich in detail, such that when the event is successfully remembered, self-reference at encoding facilitates subjective recollective experience. This view leads to the prediction that the memory advantage should be present for those items that are recollected, versus those remembered on the basis of a sense of familiarity only (Conway & Dewhurst, 1995).

Evidence has been found in support of the above prediction, leading Conway, Dewhurst, Pearson and Sapute (2001) to rename the SRE the 'self-reference recollection effect' (SRRE). As previously discussed, van den Bos and colleagues (2010) first found evidence for the specific enhancement of the recollection component of memory by using ownership to trigger self-reference (see 2.1.2). The SRRE occurred without the need for explicit self-evaluation, as the shopping task implies incidental, non-evaluative self-reference, as opposed to the trait-adjective task originally used. Thus, van den Bos and colleagues (2010) concluded that the SRRE is not limited to explicit self-evaluation tasks but may apply to a broader range of self-referential contexts, such as for example the one of the shopping task. The similarity between the self-referential memory advantage obtained through explicit self-evaluation and that elicited by ownership in the shopping task speaks to the deep influence of self on cognition (D. J. Turk et al., 2008).

3.1.4 The present investigation

3.1.4.1 The SRRE in the ownership paradigm: behavioural investigation

As recollection and familiarity were confounded in the old-new task used in Experiment 1, this prevented further investigation of if and how the ERP data reflected the specificity of the self-memory enhancement to recollection, that is, the above-mentioned SRRE (Conway et al., 2001). Following the considerations outlined in previous sections, and the limitations of Experiment 1, namely, the lack of experimental dissociation of the processes of recollection and familiarity-driven recognition, in Experiment 2 the remember-know (R-K) test will be used in conjunction with the shopping paradigm. Additionally, as in van den Bos and colleagues (2010), a further option of 'guess' will also be included (Gardiner & Richardson-Klavehn, 2000), so that remembering and knowing are independent, yet not mutually exclusive, response options. At this stage of the present investigation, ERPs will not be recorded; instead, the present behavioural investigation will also aim to determine whether the paradigm used proves viable for using in the proposed ERP investigation, as explained in detail in the following section.

3.1.4.2 The proposed ERP investigation and its viability

Besides looking to replicate van den Bos and colleagues's (2010) finding of a SRRE, another aim of Experiment 2 is to verify whether the paradigm used would produce the required number of trials associated with each type of response in order to contrast the electrophysiological differences between ownership conditions within remember responses (in other words, the ERP correlates of the SRRE). For most memory studies, according to Luck (2014) one should have at least 30 trials per participants per condition of interest, in order to reach sufficient signal-to-noise ratio. Reaching this number of trials for recollection responses in both ownership conditions would allow a valid electrophysiological investigation of the ownership SRRE.

Although the functional significance of the parietal old-new effect has been source of extensive debate (Rugg & Curran, 2007) one hypothesis is that it indexes processes that contribute to the representation of recollected information (Wilding & Rugg, 1996), or otherwise that it might index attentional orienting to recollected information (Rugg & Henson, 2002). The finding that the size of the effect is related to the amount of information recollected (Vilberg et al., 2006), supports the former hypothesis over the latter. Either way, it is of interest to the present research to investigate whether the self-reference recollection effect usually observed in behaviour can also be observed in an ownership modulation of the late parietal old-new effect. This observation would be in the form of a larger effect for self-owned items, when compared to other-owned items, amongst items that are successfully retrieved with the experience of recollection.

If the behavioural data produced a number of responses sufficient for an ERP study, such study would then be capable of investigating whether:

1. There was no modulation of ownership on the parietal old-new effect, that is, no observable difference between ownership conditions amongst ERP waveforms elicited by recognition judgements accompanied by recollection. This would signify that the modulation of the old-new effect by ownership, as found in Experiment 1, might be accounted for solely by the fact that recognition of self-owned items is accompanied by recollection to a greater extent than other-owned items. This result would still count as evidence for the specific enhancement of recollection by self-reference through ownership; however, the observed self-other differences could be accounted for, at least in principle, solely by an enhanced involvement of the same neural processes supporting recollection of non-self-referred items. In other words, this result would not directly support the involvement of self-specific neural processes in the retrieval of self-referred items.
2. A modulation of the parietal old-new effect occurred, whereby contrasts of self-other within remember responses would reveal a larger ERP response for self, compared to other. At least three potential explanations for this difference would be plausible: (a) that self-referential encoding enhances elaborative episodic representation of the original event and its recollection, and this is reflected in the late parietal old-new effect, as LPC magnitude is known to vary depending on the amount of information recollected; (b) that the retrieval of self-referential stimuli recruits self-specific regions, and activity in these regions elicits self-other differences in

the ERP; and (c) a combination of (a) and (b), whereby activity both in self-specific regions and regions that support episodic retrieval would elicit the self-other differences in the ERP.

In the following sub-section, the approach taken in designing the present experiment is described; the overall purpose of the calculations described below is that of obtaining enough epochs in each condition of interest, for the proposed ERP investigation to be attainable using such paradigm.

3.1.4.2.1 Experimental Design

Hit rates in van den Bos and colleagues (2010) suggest that, in their study, a proportion of roughly .20 of 'old' responses were familiarity-driven, 'know' responses (.178 for self-owned items, .218 for other-owned items; see Table 3.1). It is likely that, in Experiment 1, a comparable proportion of correct memory judgements was also based on familiarity, given the similarity in the encoding paradigm used. By differentiating remember and know responses, Experiment 2 allows an investigation of the self-reference recollection effect (SRRE; Conway et al., 2001). Furthermore, it allows to verify whether the number of responses obtained would be such that, in a proposed ERP investigation of the SRRE using the ownership paradigm, enough epochs would be obtained to compare the conditions of interest. In order to do this, one would need to obtain at least 30 responses (Luck, 2014) in the remember-self (SR) and the remember-other (OR) conditions, to be compared to correct rejections (CR). This would allow to investigate how self-reference (that is, the ownership manipulation) modulates the late parietal old-new effect, and if this mirrors the self-reference effect observed in behaviour, in the form of a larger ERP response for self-owned items, when compared to other-owned. With regards to sample size, according to power estimates, with a self/other/new comparison at test (repeated-measures ANOVA, 1 group, 3 factors), to reach a medium-sized effect ($f = 0.25$), with Power = .90 ($1 - \beta$; $\alpha = 0.05$), the estimated final sample size for analysis would be of 36 participants (critical $F = 3.13$).

Given that, assuming a SRE is found, the number of self-owned correctly recognised items is higher than other-owned, one would need to ensure there are enough other-owned items accompanied by correct memory judgements, or hits, to compare to self-owned hits, within 'remember' responses. According to the R/K proportion relative to other-owned items, as estimated from the accuracy data in van den Bos and colleagues (2010; see Table 3.1), OR responses would be 2.197 times OK responses (.479 divided by .218). If one wanted to reach a minimum threshold of 30 epochs for OR responses, OK responses would be estimated to 13.7 (30 divided by 2.197), resulting in a minimum required total number of other-hits of 43.7 (30 plus 13.7). In Experiment 1, this threshold was only reached by a proportion of .625 participants. To increase this proportion to .80, there would need to be an increase in number of items. In Experiment 1, a proportion of .80 participants performed at an other-hit rate of .46 or higher. However, this hit-rate was equivalent to only 37 epochs for other-hits, when total number of other-owned items was 80. In order to increase the number of other-hits to 43.7 (OR = 30; OK = 13.7) at the .80 participants threshold, presuming that such proportion of participants would still perform at an accuracy rate of .46 or higher on other-owned items, one would need 95 items (43.7 divided by .46). As the self-hit rate for participants at the proportion threshold of .80 in Experiment 1 was .52, participants would have at least 49.4 (.52 multiplied by 95) epochs for self-hits, and, according to a self-owned R/K proportion of 3.151 (.561 divided by .178), as estimated from van den Bos and colleagues (2010), they would have 37.5 (49.4 divided by 4.151 multiplied by 3.151) epochs for the SR condition.

According to the above calculations, a paradigm with 95 items per conditions would reach the number of SR and OR responses to satisfy requirements for carrying an ERP analysis comparing ownership conditions within remember responses, on at least a proportion of .80 of the total sample of participants. In van den Bos and colleagues (2010), accuracy was 2% higher for both self and other-owned items, than in Experiment 1, which had an increase of 30 items in each condition compared to van den Bos and colleagues' paradigm. If one assumed a similar pattern of decrease in accuracy in Experiment 2, then one would expect to see a further decrease of 1% for an increase of 15 items per condition. However, accuracy might not decrease linearly with item increase, and further increasing the number of items would potentially cause participant disengagement, due to length of the task; therefore, the number of items is kept to 95 per condition (with a total of 285, including new items) in Experiment 2.

Experiment 1 had a final sample size of $n = 25$ participants. Assuming that a proportion of .80 participants reaches a threshold of 30 epochs in the conditions of interest, according to estimates described above, to reach a final sample size of $n = 36$ participants, Experiment 2 will need a total sample of $N = 45$ participants. In considering the possibility that increasing the number of items to 285 caused an overall decrease in accuracy, testing a total sample of $N = 45$ participants allows the proportion of valid participants to get as low as 62.5% to still reach sufficient power ($1 - \beta = .80$; $n = 28$ participants).

With regards to K responses, according to estimates based on van den Bos and colleagues (2010), with 43.7 epochs for other-hits at the .80 proportion of participants cut-off, there would only be 25.7 epochs (K-S: 12; K-O: 13.7) for K responses collapsed across conditions. Yet with a total sample of 45 participants, the R vs. K vs. CR analysis could still be carried out on a sub-sample of participants that reached the threshold for 30 epochs in a K condition collapsed across self-other, avoiding a further increase in total number of items. Investigating patterns in K responses is only a secondary aim of an ERP version of this experiment, thus the focus remains on reaching a sufficient number of responses for items that are recollected in this behavioural experiment.

Table 3.1

Proportion Correct Responses in van den Bos et al. (2010) and in Experiment 1.

		Self				*Other*			
		R	K	G	TOT	R	K	G	TOT
van den Bos et al. (2010)	HTR	.561	.178	.042	.739	.479	.218	.050	.697
	FAR	.009	.042	.026	.051	.009	.042	.026	.051
Experiment 1	HTR		–		.712		–		.671
	FAR		–		.132		–		.132

Note. Proportion correct responses (hit rates) were calculated as number of correct responses divided by number of total items within each condition. HTR = Hit Rate; FAR = False Alarm Rate; R = Remember; K = Know; G = Guess; TOT = Total (R+K).

3.2 Method

3.2.1 Participants

A total of 52 undergraduate students (46 females, mean age 20.4 years) in the School of Psychological Science at the University of Bristol took part in the study in exchange for course credit. All participants had normal or corrected-to-normal colour vision, were dominant right-handed, and native or fluent English speakers, who reportedly lived in the UK for more than two years. Participants gave informed consent according to the guidelines set by the University of Bristol's Faculty of Science Human Research Ethics Committee (ID 73461).

3.2.2 Stimuli and Apparatus

The stimulus set comprised of a total of 285 digital images of items sold in major supermarkets; 240 of these images were the same used in Experiment 1, and 45 additional images were selected from the Bank of Standardised Stimuli (BOSS v.2; Brodeur, Guérard & Bouras, 2014), that matched the requirements of the initial set (2.2.2). Each image was edited so that each item appeared on a white background, with a black or coloured border (blue/red) and resized to 250 x 250 pixels at a resolution of 149 dpi. The items were divided in three sets of 95, matched on category membership (food and drink, clothing and accessories, household items, electronics) and name length. Assignments of sets to conditions (self, other, new) was counterbalanced across participants following a Latin square design. The experiment was programmed and run using the MATLAB software v.R2016. Stimuli were presented on a DELL PC monitor at a resolution of 1920 x 108, 60Hz.

3.2.3 Procedure

Participants were seated at the PC in the test room and invited to fill in the relevant paperwork. They were then given on-screen instructions whilst the experimenter was present to answer any questions on the experiment. The experiment consisted of two tasks: an encoding phase, followed by a memory test. At the beginning of the experiment, participants were informed they would need to complete two 'sorting' tasks during which they would have to sort items in different categories; however, they were unaware their memory for the items encountered during the first task would be later tested in the second task.

3.2.3.1 Encoding

For the encoding task, participants were informed they would need to undertake a computerised 'shopping task'. During the on-screen instruction phase, they were assigned a shopping basket (either blue or red), and the experimenter was assigned the other basket. They were informed that they would see shopping items on the screen, one by one, and each of these items would be assigned by the computer, either to them or the experimenter. A coloured blue/red border would appear around the item, to denote who the item was assigned to. The participant's task would be to 'sort' the items into the correct baskets by colour matching the ownership cue to the colour of the basket, using either the left/right arrow key depending on location of the baskets, whilst imagining either they or the experimenter coming into ownership of the current item. Blue/red basket assignment conditions were counterbalanced between participants, and baskets changed positions so that the blue basket would appear on the left side for half the trials, and vice versa. Figure 3.1 represents a full encoding trial sequence, including presentation times. There was an inter-trial interval of 1 second, and 38 trials for each block, resulting in a total of 5 blocks (190 trials). Half of items in each block were self-owned, the other half other-owned. Order of presentation of the items was randomised.

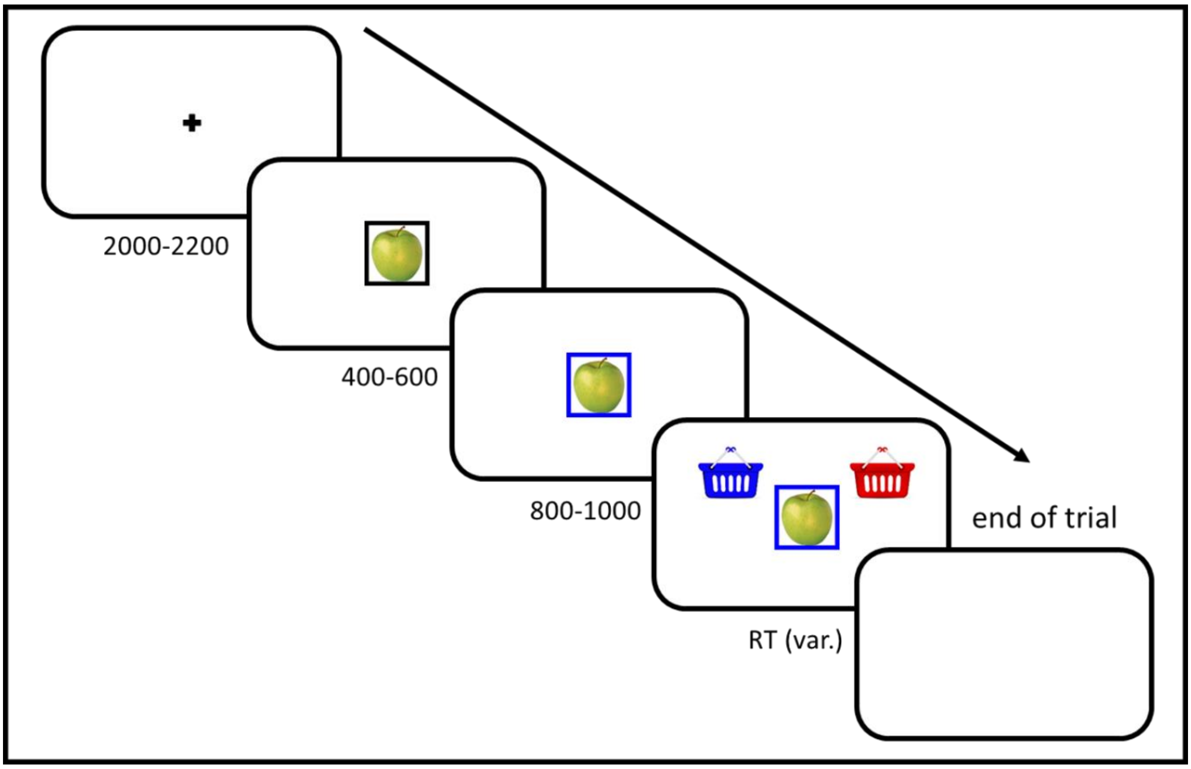

Figure 3.1 Example trial for the encoding task of Experiment 2. Times are in milliseconds. RT (var.) = reaction time (variable).

3.2.3.2 Test

After a short break, participants were informed that the second task they needed to complete would be a memory test. For this task, participants received print instructions. They were told they would be presented with each of the items they had seen during the encoding task, plus some novel items they had not previously encountered. The participant's task would be to indicate first whether they recognised the item from the encoding task ('yes'), or the item was novel ('no'). Then, in case they recognised the item, they were asked to make a judgement on whether recognition was accompanied by recollective experience, or by strong feelings of familiarity in the absence of any recollective experience. If recognition brought back to mind something they consciously experienced at the moment of first seeing the item, they were instructed to respond 'remember' ('R'), whereas if they did not recollect anything they experienced then, they were instructed to respond 'know' ('K'). The experimenter made sure that participants did not interpret this difference as being "sure" or "unsure" and explained that, in both cases, the response would mean that they were confident they had seen in the item in the previous task. Finally, they were also given a further response option of 'guess' ('G'), in case their response was a guess, or a mistake (see Appendix B for the full test procedure instructions that were given to participants, adapted from Gardiner & Richardson-Klavehn, 2000). The experimenter then asked participants to confirm they understood the difference between remembering and knowing, in their own words. Figure 3.2 represents a full trial sequence, including presentation times. There was an inter-trial interval of 1 second, and 57 trials for each block, resulting in a total of 5 blocks (285 trials). Order of presentation of the items was randomised.

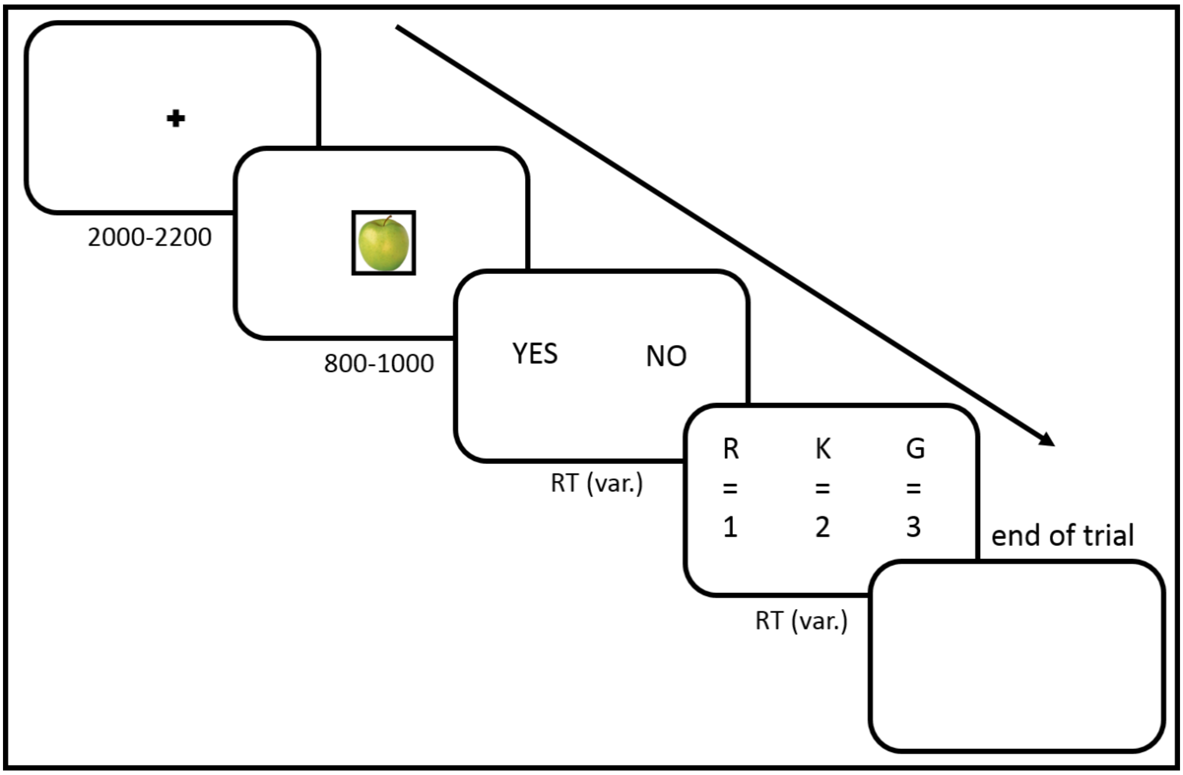

Figure 3.2 Example trial for the memory test of Experiment 2. Times are in milliseconds. RT (var.) = reaction time (variable).

3.3 Results

3.3.1 Data processing

Out of the total sample of 52 participants who took part in the study, 3 did not complete the experiment due to machine failure, leaving a total sample of *N* = 49 for analysis. Data was analysed using the IBM SPSS software (v.24).

Participants sensitivity scores (*d′*) and bias scores (*c*) for the yes/no memory test were taken into account as normalised c scores (*c′*, or *c-prime*; obtained by dividing *c* by *d′*; see Macmillan & Creelman, 1990). Analysis of these scores by visual inspection of scatterplots and boxplots revealed that most participants had a bias for responding 'no' (positive scores of *c′*); for participants whose overall accuracy was lowest, *c′* scores were highest. The two criteria of overall accuracy and *c′* were used in conjunction to exclude participants on the basis of low engagement with the task, denoted by overall accuracy scores, and low sensitivity/high response bias, denoted by *c′* scores. Out of the final sample of *N* = 49, 8 participants were excluded from the memory analysis as they performed poorly in the memory test, as denoted by a high bias to respond 'no' (*c′* > 1) and low overall accuracy (≤ .50 proportion correct). One further participant was excluded on the basis of their *c′* score only (-1.2; overall accuracy = .69), as it indicated a bias to respond 'yes' that considerably diverged from the trend of *c′* plotted against overall accuracy (see: Figure 3.3). This left a sample of 40 for the memory analysis (see Appendix C for a full list of participants with memory test responses).

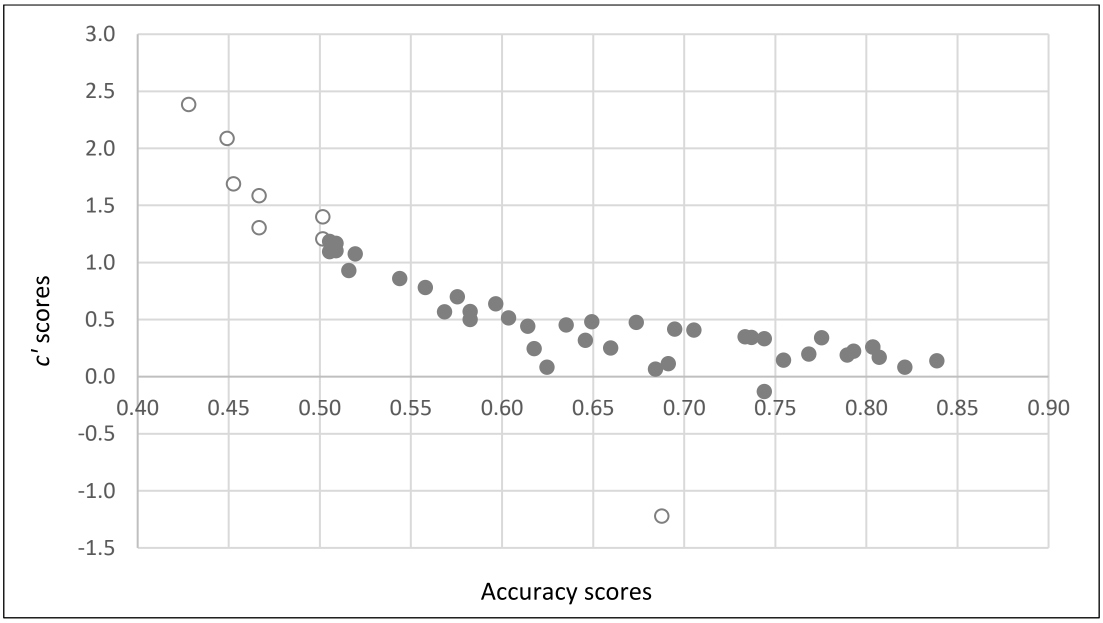

Figure 3.3 Normalised c scores (*c′*) plotted against overall accuracy at memory test in Experiment 2. White-filled dots denote participants excluded from the analysis. One participant is not represented on the graph because of a very high *c′* score (values: x = 0.39, y = 11.5); this participant was also excluded from the analysis.

3.3.2 Encoding

During the encoding phase, accuracy data from 3 participants was missing due to a recording failure, leaving a sample of 46 for encoding accuracy analysis. Latency data from the encoding phase was instead analysed for the full sample. During the encoding phase, participants were very accurate overall (99%); the difference in mean accuracy scores between conditions was not significant, [$t(1,45) = 0.688$, $p = .495$], nor was the difference in mean latency scores [$t(1,48) = 0.561$, $p = .578$].

3.3.3 Memory

The final sample for memory analysis, after the above participant exclusion, was $n = 40$. Due to a script recording fault, $n = 4$ participants were excluded from the memory awareness analysis as their remember/know/guess responses were not recorded correctly; however, their data was used for the old-new analysis. This left a final sub-sample of $n = 36$ for the memory awareness analysis.

3.3.3.1 Overall accuracy: old-new test

Overall mean accuracy in the final sample was .66 ($SD = .10$). Hit rates (HRs) and false alarm rates (FARs) were calculated; FARs were subtracted from HRs for each response type for correction (see Table 3.2). Resulting corrected hit rates were submitted to a single-factor (ownership: self or other) repeated measures ANOVA, which revealed a significant main effect of ownership, [$F(1,39) = 6.803$, $MSE = 0.006$, $p = .013$, $\eta_p^2 = .149$]; whereby participants recognised a higher proportion of self-owned items ($EMM = .443$, $SE = 0.034$) than other-owned items ($EMM = .399$, $SE = 0.027$).

3.3.3.2 Memory awareness: R-K test

As guess responses were low overall (with an average proportion of .03), they were not included as a factor in the memory awareness analysis. A 2 (ownership: self or other) x 2 (memory awareness: remember or know) ANOVA was applied to remember and know corrected hit rates which revealed a main effect of ownership, [$F(1,35) =6.895$, $MSE = 0.003$, $p = .013$, $\eta_p^2 = .165$]. Overall, more items owned by self ($EMM = .213$, $SE = .019$) were recognised, versus items owned by other ($EMM = .188$, $SE = .014$).

This analysis also revealed an interaction between ownership and memory awareness, [$F(1,35)= 5.342$, $MSE = 0.016$, $p = .027$, $\eta_p^2 = .132$]. Analysis of simple contrasts revealed an ownership effect within remember responses, whereby the mean difference between the proportion of remembered self-owned and other-owned items ($MD = .073$, $SE = 0.027$), was statistically significant ($p = .012$), with a higher proportion of self-owned items remembered ($EMM = .317$, $SE = 0.032$) than other-owned items ($EMM = .244$, $SE = 0.025$). On the contrary, there was a higher proportion of other-owned items (*EMM* = .133, *SE* = .023) recognised on the basis of knowing than self-owned items (*EMM* = .109, *SE* = .020), however this difference was not significant (p = .182).

3.3.3.2.1 I-Know correction

In a classic R-K paradigm with only two response options (Tulving, 1985), these responses are assumed to be mutually exclusive; that is, 'remembering' and 'knowing' can never co-occur, because participants respond either remember/R or know/K for each item, never both. If a K response is given only when there is no recollective experience, this type of response likely underestimates the probability that an item is familiar (Yonelinas & Jacoby, 1995), as familiarity can co-occur with recollection. When guess/G is also included as a response option, presumably the two responses are no longer mutually exclusive. However, as G responses were low overall in the present experiment (see Appendix C), the mutual exclusivity of the two responses may still constitute an issue. For this reason, Yonelinas and Jacoby's (1995) independence correction for know responses was applied to the present analysis. To estimate the probability that an item is familiar (F), one can divide the proportion of K responses by the opportunity the subject has to make a K response (1 – R), according to the following formula (Yonelinas & Jacoby, 1995, p.630):

$$[\ F = K/(1 - R)\ ].$$

Independent-know (I-Know) proportions calculated with this formula are also reported in Table 3.2.

Following the above correction, a further 2 (ownership: self or other) x 2 (memory awareness: remember or independent-know) ANOVA was applied to remember and I-know corrected hit rates. There was a significant main effect of ownership, [$F(1,35) = 7.917$, $MSE = 0.009$, $p = .008$, $\eta_p^2 = .184$]. Overall, more items owned by self (*EMM* = .275, *SE* = .026) were recognised, versus items owned by other (*EMM* = .230, *SE* = .017).

In this analysis, the interaction between ownership and memory awareness, [$F(1,35) = 3.152$, $MSE = 0.009$, $p = .085$], was not significant. More self-owned items (EMM = .317, SE = .032) than other-owned items (EMM = .244, SE = .025) were recollected, and this difference (MD = .073, SE = .027) was significant (p = .012). More self-owned items (*EMM* = .233, *SE* = .029) than other-owned items (*EMM* = .217, *SE* = .024) were recognised on the basis of familiarity, however this difference was small (*MD* = .015, *SE* = .016) and not significant (p = .349). The pattern of responses is shown in Figure 3.4.

Table 3.2

Mean Proportions of Correct Responses and False Alarm Rates for the Test Phase of Experiment 2.

	Total		*Remember*		*Know*		*I-Know*	
	Self	Other	Self	Other	Self	Other	Self	Other
HTR	.588 (.168)	.545 (.133)	.361 (.174)	.289 (.146)	.193 (.106)	.216 (.118)	.317 (.159)	.301 (.233)
FAR	.145 (.107)		.045 (.062)		.084 (.086)		.084 (.086)	

Note. Means and standard deviations (in parentheses) of raw hit rates (HTR) and false alarm rates (FAR), as a function of ownership condition, for the overall accuracy and memory awareness analyses. I-Know = Independent-Know.

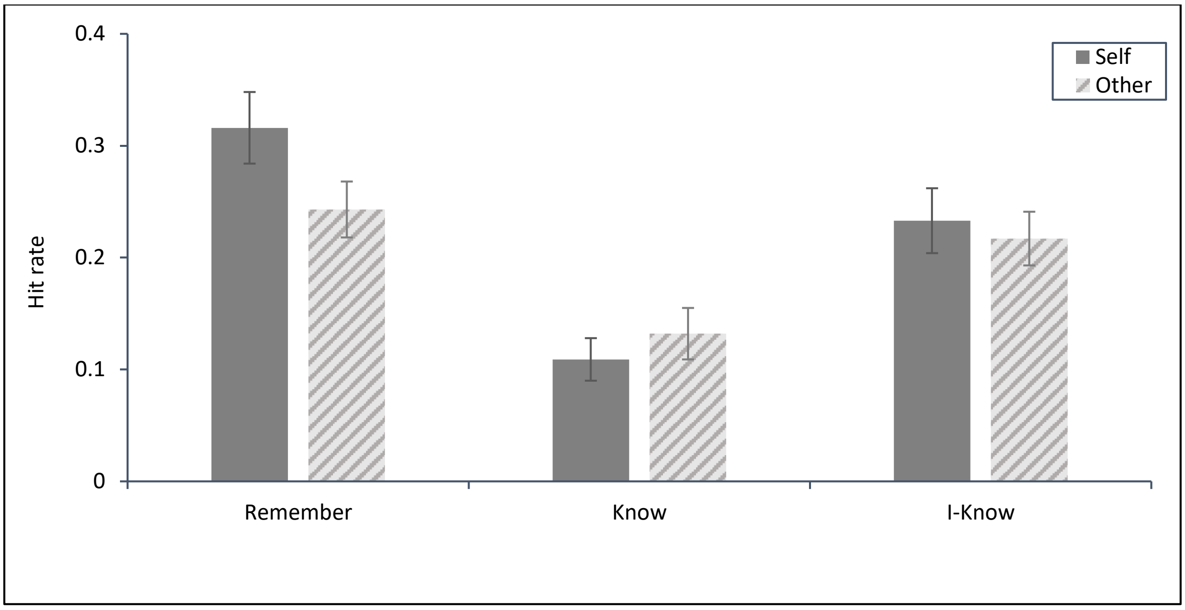

Figure 3.4 Remember, know and I-know corrected hit rates shown as a function of ownership condition for Experiment 2.

3.3.4 Viability of proposed ERP investigation

Further analyses revealed that only a proportion of .60 participants performed at a rate of .46 for other-owned hits (the original expectation was that this would occur for a proportion of .80 participants). Out of the sub-sample of n = 36 participants used for the memory awareness analysis, only 11 (a proportion of .31) reached the number of responses required (>=30) for an ERP comparison of ownership conditions within remember responses (full response data is reported in Appendix C).

3.4 Discussion

3.4.1 Behavioural findings

In the present experiment, during the encoding phase, participants sorted a series of objects either assigned to themselves (self-owned), or to the experimenter (other-owned) into shopping baskets. Later on, when re-presented with the already seen items (old), in addition to novel items (new), they were asked to make an old-new distinction, and in case items were recognised as old, they were asked to make a further distinction on whether they recollected seeing the items in the previous task (remember), they just had a strong feeling of familiarity with the items from the previous task (know), or neither of the two (guess).

3.4.1.1 SRE

Results showed that, when comparing hits (correctly recognised old items) and misses (old items incorrectly classified as new), a 'self-reference effect' (SRE) was found, whereby more items assigned to self at encoding were recognised at test, compared to items assigned to other. This finding contributes to a robust literature on the SRE (see Symons & Johnson, 1997 for a review), and specifically, replicates the findings of Experiment 1, and those of Cunningham and colleagues (2008), that self-reference enhances memory even when it is incidental and non-evaluative, such as in the present experiment with the use of the shopping task. By dividing items into self-owned and other-owned categories, participants were not directed to perform any elaborative self-referential encoding, such as, for example, in a standard trait-rating task (e.g., Kelley et al., 2002), yet the memorial pattern of self-referential encoding still emerged in the memory data.

3.4.1.2 SRRE

According to dual-process models of recognition memory, a retrieval cue (such as a studied item presented during test phase), can elicit two different types of memory signal: a multi-dimensional 'recollection signal', providing qualitative information of the study event, including its context, and a scalar 'familiarity signal', supporting a simple judgement of the prior occurrence of the item (Rugg & Vilberg, 2013). When, in the present data, correct memory judgements were separated into those accompanied by recollection (remembering) and those that were not (knowing), the self-referential memory enhancement only occurred within the former, and not the latter. Given that the R-K task is a reliable experimental dissociation of the two processes of recollection and familiarity (Yonelinas, 2002), the effect found is better described as the self-reference recollection effect (SRRE; Conway et al., 2001), as the two states of memory awareness of recollection and familiarity were affected differently by ownership at the time of retrieval. This finding provides further evidence for the hypothesis that self-reference through ownership enhances recollection selectively, replicating previous findings by van den Bos and colleagues (2010; also see D. J. Turk et al., 2013).

These findings speak to the deep influence of self on cognition (D. J. Turk et al., 2008), through which self-relevant information (such as owned objects), is subject to enhanced processing at encoding, and enhanced episodic memory retrieval. It has been argued that self-reference aids elaboration through the activation of self-schemas, by which participants apply extant self-knowledge to representations of self-referenced information at encoding (Symons & Johnson, 1997). Consistent with this view, in the present study, a few participants reported verbally, during debrief, that as they performed the shopping task they were “creating a narrative” on how they would use the objects gained during the task. Moreover, attention and affective systems might also contribute to the ownership effect; in particular, self-ownership cues are likely to attract attention and also elicit affective arousal (D. J. Turk et al., 2011).

3.4.2 Viability of Proposed ERP Investigation

A limitation of Experiment 1 was that the old-new paradigm used at test did not differentiate between the two processes of familiarity and recollection, therefore not allowing further analysis of the modulation of ownership on the ERP correlates of recollection. Besides replicating previous findings, another aim of Experiment 2 was to investigate whether such paradigm would be employable in a proposed ERP investigation of the SRRE. Specifically, the aim was to evaluate whether enough responses would be obtained in the self and other conditions within remember memory judgements, to compare ERP correlates of recollection between ownership conditions. The paradigm used in the present investigation was designed with the aim of obtaining enough responses to make such comparison possible (see 3.1.4.2.1).

However, there was a sharp overall mean proportion accuracy decrease compared to Experiment 1 (see 3.3.4). This decrease in accuracy might have been due to the length of the task and the number of items, which posed strain on participant engagement. When considering the minimum number of responses required for a successful ERP comparison of self and other conditions within the remember condition of interest, this number (30 epochs) was only reached in 11 participants. This result speaks clearly to the limitations of ERP as a technique for scientific investigation of cognitive processes; more specifically, obtaining enough epochs for comparison of different conditions of interest, whilst keeping the task engaging for participants without compromising their performance, is a well-discussed challenge of using ERP technique (e.g., Wilding & Ranganath, 2011).

In conclusion, the ERP investigation proposed is not viable with the use of the present paradigm. Thus, the limitations of Experiment 1 could not be overcome by modifying the paradigm with the use of the remember-know task, beyond allowing for an estimate of proportions of R-K responses within correct memory judgements. In this way, the finding of a SRRE using the present paradigm can still be of use in interpreting the ownership modulation of the ERP old-new effect found in Experiment 1 (for further discussion of this point, see 4.1).

4 General Discussion

4.1 Summary of Present Findings and Limitations

The present investigation included two experiments. In the first experiment, participants completed the shopping paradigm, and a subsequent old-new memory test, whilst event-related potentials (ERPs) were recorded (Chapter 2). In a second experiment, participants again completed the shopping task, followed by a remember-know memory test (Chapter 3).

In both experiments, a self-reference effect (SRE; Symons & Johnson, 1997) was found, whereby participants remembered more items that were assigned to self during the shopping task, than items assigned to other. Moreover, in the second experiment, the SRE was found only amongst items that were recognised with the addition of episodic detail of the first encounter of the items. These findings replicated those of Cunningham and colleagues (Cunningham et al., 2008; van den Bos et al., 2010) first, in that ownership can trigger self-referential effects in memory, and second, in that the self-referential memory advantage assigned to self-owned objects is specific to recollective experience. This provides further behavioural evidence for the claim that self-reference enhances episodic recollection selectively, and that the self-reference effect can thus be better defined as 'self-reference recollection effect' (SRRE; Conway et al., 2001). The SRRE suggests a close association between the self-referential encoding context, and later recollective experience of self-referred information during retrieval. It has been argued that a sense of self in the past is necessary for such recollective experience to occur (Conway & Dewhurst, 1995).

In the case of the present enquiry, self-reference was triggered through the assignment of temporary, fictitious ownership of objects in a computerised experiment, yet this was still sufficient to elicit the effect. This speaks to the extended nature of the self, by which one can consider possessions as a self-extension (Belk, 1988). Owned objects have been argued to benefit from a special psychological status, such that ownership of an object leads one to evaluate it more favourably merely because said object has an association with its owner, and even to perceive it as more valuable (Beggan, 1992; Kahneman et al., 1991). The present findings provide more evidence that self-item associations elicited implicitly through psychological ownership bring a memory advantage comparable to that brought by explicit, evaluative encoding of trait adjectives, albeit a smaller one (Cunningham et al., 2008).

The present enquiry also investigated the neurophysiological correlates of the ownership SRE. A P300 effect was found in the first experiment, whereby self-ownership cues yielded a larger P300 component than other-ownership cues. This indicates that the enhanced attentional processing characteristic of self-relevant stimuli can be elicited by the act of taking ownership of an object, and that said enhancement can be triggered online by arbitrary objects that one has no personal history with, such as the shopping items used in the present investigation (D. J. Turk, van Busell, Brebner et al., 2011). The attentional bias observed might function to enhance subsequent memory for self-relevant objects (Cunningham et al., 2013). The P300 might be an electrophysiological correlate of the self-relevant attentional modulation described by Humphreys and Sui (2016) in their SAN model (see 1.3.2). D. J. Turk, van Bussel, Waiter and Macrae's fMRI study (2011) found that regions involved in modulating attention to salient objects are activated during the encoding of self-owned stimuli in the shopping task (see also below, 4.1.1).

Moreover, as the P300 effect was found to persist amongst items that were subsequently remembered during the test phase, this also indicates that the attentional bias observed might contribute to qualitative memory processes beyond increasing the quantity of recognised objects. As further support for this claim, an ownership modulation of the ERP late old-new effect was found, whereby correctly recognised self-owned items elicited a late positive component (LPC) larger in amplitude, when compared to other-owned items. As the amplitude of the LPC has been found to be sensitive to the amount of information retrieved (Vilberg et al., 2006), this finding might indicate that, beyond a larger number of recognised items, self-reference in the present paradigm also resulted in an enhancement of the quality of memories about said items. Yet, as the first experiment did not include a memory test which assessed the amount of information retrieved, there was no direct behavioural evidence that participants retrieved more information about self-owned items, compared to other-owned items. Furthermore, it was not possible to dissociate the neurophysiological correlates of recollection and familiarity-based recognition, as the old-new test used did not employ such experimental dissociation. However, in the absence of such overt behavioural measure, the ERP data still offers a covert measure indicating a modulation of self-reference on memory retrieval, which is likely qualitative in nature.

In the second experiment, the R-K task (Tulving, 1985; Gardiner & Richardson-Klavehn, 2000) was used to dissociate between the processes of recollection and familiarity during the test phase of the shopping paradigm. One aim of this experiment was to test the validity of such R-K version of the paradigm for use in a proposed ERP investigation of self-referential effects on the recollection component of memory during retrieval. However, results indicated that such paradigm would not produce the required amount of data for a successful ERP analysis (3.3.4). Although ERPs were not recorded during this experiment, the finding of a SRRE provided further behavioural evidence that self-reference through ownership enhances recollection specifically. This enhancement might have elicited the modulation of the LPC component seen in the previous ERP experiment. However, what exactly is driving this modulation remains unclear and is a major limitation of the present investigation.

According to dual-process accounts of recognition memory (Yonelinas, 2002), the neural activity elicited by correctly recognised items as recorded in the first experiment would have to be the sum of the neural correlates of familiarity and recollection. One possible interpretation of the ERP findings is that, because a larger number of items owned by self are accompanied by recollection, this resulted in a larger LPC component, when compared to items owned by other. This follows that the LPC component is found to be larger for items that are recollected, versus those that are recognised on the basis of familiarity (Wilding & Ranganath, 2011). Thus, in a comparison of ERP waveforms between ownership conditions, without further distinguishing responses according to the presence or lack of recollection as measured behaviourally, any difference could be accounted for by a greater contribution of the ERP correlates of recollection to the grand-averaged waveform for self-owned items, compared to that of other-owned items.

An alternative explanation for the findings of the present ERP investigation is that, even amongst items that are recollected, the ones processed within a self-referential context are characterised by a richer recollective experience, with more information retrieved about each item and the episode of its initial encoding. In this case, the LPC component would be modulated by ownership even amongst responses characterised by recollection, because of its correlation with the amount of information retrieved (Vilberg et al., 2006). However, as seen previously, it is difficult to design an ERP paradigm that would produce the required number of responses in order to test this hypothesis.

Despite the above limitations, the present findings indicated that self-reference through ownership is characterised by attentional biases at encoding, and that these biases contribute to qualitative aspects of memory, in the form of more items recognised with the additional recollection of the encoding episode. Potentially, more information is also retrieved about said recollected items, when compared to non-self-referred items, although the last claim is speculative and could not be verified using the data collected.

4.1.1 The Present Findings in the Wider Context and Suggestions for Further Research

The main motivation driving the present inquiry was to investigate self-referential biases on attention and memory and their neurophysiological correlates, by using ownership as a means of triggering self-reference. ERP-technique provides the ability to measure brain activity in real time and can provide some evidence that different networks might be contributing to the differences in the neural activity observed; moreover, insight can also be gained from the timing of ERP effects, into the functional significance of said differences (Wilding & Ranganath, 2011). However, a limitation of ERP-technique is that it does not provide a clear indication of the anatomical source of the brain activity recorded at the scalp (Luck, 2014). With regards to the brain networks which might support the self-referential effects found, specifically, the electrophysiological differences observed between ownership conditions in the present data, one can turn to other evidence obtained using neuroimaging techniques that provide more spatial accuracy, such as event-related fMRI. The high spatial resolution that is characteristic of functional neuroimaging studies means that such evidence can be of use in interpreting ERP data, especially when the data is obtained in comparable experimental conditions.

When interpreting results from ERP research one has to acknowledge that, as Rugg and Coles (1995) put it, “ERPs provide information about *only a fraction* [emphasis added] of the neural activity associated with the processing of a stimulus” (p.35). As a consequence, the ERP correlate of a cognitive process of interest cannot and should not be equated to its neural signature. With this caveat in mind, the present ERP enquiry was motivated by a larger theoretical framework attempting to describe self-referential processing in its anatomical and functional states, particularly when triggered by object ownership (1.4.1). In relating the present findings to such framework, it is also important to consider which neural process(es) are directly reflected by the ERP components which were the focus of the analyses of present data (specifically, the P300 and the LPC).

In their fMRI investigation of the shopping paradigm, D. J. Turk and colleagues (2011) identified activity in an ‘ownership network’ of brain areas that was predictive of the memory bias. However, they did not record fMRI during the test phase, lacking an investigation of which neural networks supported the ownership self-referential bias at retrieval. The ownership network includes areas known to be recruited for modulation of attention to salient stimuli (dorsomedial prefrontal cortex and caudal anterior cingulate cortex), which also overlap with the cortical medial structures (CMS) identified by Northoff and colleagues (2006) as key areas for the processing of self-relevant information. The finding of a P300 effect during the shopping paradigm indicates that self-owned objects benefit from enhanced attention that is triggered online at the moment of encoding. As Conway and colleagues (2016) have proposed, this attentional enhancement might be mediated by the self-attention network (SAN) identified by Humphreys and Sui (2016), as part of a larger self-relevance system (SRS) comprising the default mode network as its core. The SRS might function to ensure an enhancement of attention towards self-relevant stimuli via the SAN, and the forming of memories that are rich and episodic in nature (1.3.2). As the P300 component has been proposed as an index of inhibitory neural activity that functions to facilitate memory retention (Polich, 2011), the P300 effect seen in the present data might be an index of attentional processes that contribute to memory retention of self-relevant information, such as self-owned objects in the present paradigm.

With regards to the neural generators of the old-new effects, in their review of event-related fMRI evidence from a dual-process perspective, Vilberg and Rugg (2008) identified retrieval-related activity in inferior parietal cortex as associated with successful recollection. Activity in inferior parietal cortex might be driving the self-other differences observed in the LPC, if these differences in electrophysiology arose purely because of a higher number of recollected self-owned items, compared to other-owned, as explained in the previous section. In this sense, the involvement of self-specific neural networks in the brain would not be necessary for eliciting the observed differences. An alternative hypothesis is that the modulation of the LPC observed could also be elicited by activity in regions supporting both episodic memory processes and self-referential cognition. In a more recent review of fMRI findings regarding the functional neuroanatomy of successful memory retrieval, Rugg and Vilberg (2013) found further evidence for the proposal that specific brain regions, (the hippocampus, parahippocampal cortex, retrosplenial/posterior cingulate cortices, lateral parietal cortices, and medial prefrontal cortex) are part of a content-independent network which is activated during retrieval accompanied by recollection. They further proposed that this “general recollection network” (p. 257) partially overlaps with the default mode network (DMN; Buckner et al., 2008), and also with brain regions that activate during the mental construction of future-oriented, self-relevant scenarios (Addis, Wong & Schacter, 2007). They argued that these overlaps in activity might signify the common engagement of these brain regions in supporting the representation and retrieval of episodic information within self-directed cognition.

In yet another fMRI study, Andrews-Hanna, Reidler, Sepulcre, Poulin and Buckner (2010), proposed that the DMN has two major components that meet on a ‘midline core’. According to their data, one such component, the ‘medial temporal lobe (MTL) sub-system’, showed increased activity when participants imagined future scenarios. This result provides further evidence that the DMN plays a major role in both the remembering of the past and imagining of the future (Addis, Wong & Schacter, 2007). In contrast, a second component of the DMN, the ‘dorsal-medial prefrontal cortex (dMPFC) subsytem’, was found activate when participants considered their current mental states, and in particular, it was correlated with self-referential cognitive processes. The midline core, comprising the antero-medial prefrontal cortex (aMPFC) and PCC, exhibited self-related activity, independently of temporal context, thus showing functional characteristics of both sub-systems. These areas have been found to activate during self-referential tasks (D’Argembeau et al., 2005), although it is noted that Qin and Northoff (2011) observed that regions of the DMN comprising said midline core (MPFC and PCC) were not areas involved in self-specific rest-stimulus interaction (1.3.1).

An investigation of functional neuroanatomy per se was not included in the present enquiry. As ERP-technique as a means of investigation lacks the spatial precision of functional neuroimaging techniques, it does not allow one to draw conclusions about which specific brain regions are involved in the process(es) of interest (Rugg & Coles, 1995; Luck, 2014). Despite this limitation, observing qualitative differences in the topography between effects can also be taken as evidence for the involvement of different neural networks supporting such effects. The self-other differences found in the present study during retrieval might be supported by the midline core network, identified by Andrews-Hanna and colleagues (2010) as a possible site of convergence for networks supporting memory retrieval, and self-referential processing. A future study could use event-related fMRI during the retrieval phase of the shopping paradigm to verify whether the ownership self-reference effect is indeed supported by the network identified by Andrews-Hanna and colleagues (2010) as involved in both episodic memory and self-referential cognition.

4.2 "Out of the Lab": Potential Applications of the Present Research for the Enhancement of Learning

Beyond gaining a theoretical understanding of how the self-construct impacts on cognition, further research could investigate potential applications of self-referential biases on attention and memory in real-life scenarios. For instance, the fact that self-referencing is a trigger of mechanisms that enhance task engagement such as attention and affective arousal (D. J. Turk, van Bussel, Waiter & Macrae, 2011) makes it a potential tool for the enhancement of learning in the classroom. Activation of the self-construct might also support further elaboration and organisation of self-referred information (Klein & Loftus, 1988). There is evidence that an adult-like SRE develops between the ages of 7 and 10 years (Halpin, Puff, Mason & Marston, 1984; Hammen & Zupan, 1984; Pullyblank, Bisanz, Scott & Champion, 1985; cited in Cunningham, Vergunst, Macrae and Turk, 2013). D. J. Turk and colleagues (D. J. Turk, Gillespie-Smith, Krigolson, Havard, Conway & Cunningham, 2015), tested an application of self-referencing in the classroom on 7- to 9-year-olds, wanting to investigate whether self-referential encoding could enhance engagement and spelling performance.

D. J. Turk and colleagues (2015) carried out two experiments in which they used a self-referential version of a standard literacy task used in learning of novel words, whereby pupils first copy the words to be learned, and then use them in generating a sentence. The first experiment examined the impact of self-reference on the learning of nonsensical words, specifically, fictitious alien characters (e.g., "Arror"). After copying the words, pupils either included them in a sentence which had themselves as a subject (in the self-reference condition), or another alien character named "Splay" as subject (in the other-reference condition). D. J. Turk and colleagues (2015) predicted that pupils in the self-reference condition would generate longer sentences, as a measure of task engagement, and perform better in spelling, when compared to pupils in the other-reference condition. Examples of generated sentences included, respectively, “Me and Arror like to swim” (self-reference), as compared to “Splay and Arror went swimming in the sea and had lots of fun” (other-reference). Results showed that self-referencing increased both task engagement and spelling performance, as predicted, compared to other-referencing.

In their second experiment, D. J. Turk and colleagues (2015) investigated the self-referential effect on the learning of real vocabulary, to test the application of self-referencing as a teaching tool. Contrary to their first experiment, where the other-referent was an unfamiliar alien character, in their second experiment the other referent was the well-known fictional character Harry Potter. Moreover, this time pupils undertook both the self- and other-referent tasks. Again, pupils were asked to copy novel words, and use them in self-generated sentences beginning with either themselves (“I…”) or the other-referent (“Harry…”) as a subject. Pupils’ spelling for the learned words was then tested individually, four days after. D. J. Turk and colleagues (2015) replicated their initial findings of a SRE in spelling, suggesting that the application of self-referencing resulted in an enhancement of learning also as applied to real vocabulary.

D. J. Turk and colleagues (2015) did not find any correlation between sentence length and spelling performance, even though sentences generated with self-reference contained more words compared to other-reference. This result suggested that the improvement seen in spelling performance could not be accounted for solely by an increase in engagement as measured by the length of the sentences generated. They argued that other elements of academic engagement which were not measured, for instance positive affect, might be better predictors for learning outcome, when using self-reference. Nevertheless, their study is an example of how self-referential learning manipulations can provide a “high-impact, cost neutral and valuable application of cognitive science to education” (D. J. Turk et al., 2015, p.59).

4.2.1 Application of the LPC as a Marker of Long-Term Learning

In an educational context, it is difficult to determine, at time of learning, whether particular teaching methods are efficient in helping students encode, consolidate and later retrieve knowledge. Wanting to search for a biomarker of long-lasting learning that could be useful to determine which teaching methods are the most efficient for memory consolidation, K. W. Turk and colleagues (2018) investigated subsequent memory performance using ERP-technique, in a real-life learning paradigm. Their sample constituted of thirty-four medical students (20-30 years old) enrolled in a 16-week introductory anatomy course at Boston University. All learning occurred in the classroom, as opposed to what would be an ‘encoding phase’ in a standard ERP paradigm. Students were also invited to the lab and presented with anatomical terms from the course at three time points: (1) before the course start date (baseline), (2) immediately after the course end date, and (3) six months after the course end date. Participants were presented with the anatomical terms and asked to rate them using the responses: 'can define' (CD), 'familiar' (Fam), or 'don't know' (DK). During the second session in the lab, ERPs were also recorded whilst participants made these ratings. Electrophysiological responses recorded immediately after the course were then separated according to subsequent memory performance six months later.

K. W. Turk and colleagues (2018) found that most terms recollected as definable terms during the second session were still recollected six months later (60.5%), or became rated as familiar (34.4%). Only 5.1% of terms rated as definable during the second session were completely forgotten, indicating that recollection, as measured behaviourally immediately after the course, was a strong predictor of long-term retention. Most interestingly, their ERP results revealed that the LPC component was a predictor for the long-term recollection of the anatomical terms. Specifically, a larger LPC amplitude occurring 700-1000ms post-stimulus over the left parietal scalp was seen for stimuli that were subsequently recollected 6 months later (CD), compared to those stimuli recognised as familiar (Fam), and those that were forgotten (DK). Moreover, the FN400 component distinguished between later Fam versus DK responses, as well as CD versus DK responses, but not CD versus Fam responses.

K. W. Turk and colleagues (2018) concluded from their findings that the LPC alone predicted later recollection, as a potential marker of high-quality, long-lasting learning, whereas the FN400 acted as a marker for general familiarity. Their behavioural findings also indicated that recollection responses alone held predictive power about the likelihood of long-term retention of the terms. Their study provided new knowledge about the LPC as a marker of real-life, course-based learning, which predicted memorial strength several months after the initial learning of the course material. These findings have relevance for educational curriculum development, as the effectiveness of teaching methods could be tested even at the end of a particular lesson, using LPC as a predictor of long-term retention of taught material.

The LPC effect found by K. W. Turk and colleagues (2018) is similar to that found in the present enquiry; however, the learning of course material by the college students who participated in their study likely involved intentional elaboration and organisation of the material for its subsequent retention, probably well-motivated by wanting to succeed on the anatomy course. On the contrary, in the present enquiry, participants were not learning with the awareness their memory for the items would be later tested, nor were they motivated to "do well" by external factors, as their credits would be granted independently of their performance on the tasks. Despite this, the self-referential memory enhancement still occurred, although its long-term impact was not measured.

The findings of K. W. Turk and colleagues (2018) provide new ideas for ways in which the effectiveness of the application of self-reference to the enhancement of learning could be tested by using ERP-technique. If the LPC is indeed a predictor of long-term retention, then applications of self-reference in the classroom, such as the one described in the previous section, could be tested for effectiveness shortly after the self-referential learning has occurred. It is acknowledged that testing school pupils in the EEG-lab can prove quite difficult for logistical reasons. Yet, new low-cost, portable EEG equipment has been flourishing in recent years, allowing researchers to bring their research “out of the lab”, in more realistic settings. For instance, Krigolson and colleagues (Krigolson, Williams, Norton, Hassall & Colino, 2017) validated the use of the portable EEG equipment ‘MUSE’ (InterAxon Inc.), for carrying out ERP research. They have since then been using MUSE to gather ERP data in a number of settings, including reinforcement-learning (e.g., Walsh et al., 2019). Given the potential for self-reference to be applied as a learning enhancement technique, further research could test the viability of its application in the classroom, as well as other learning settings, through the use of the LPC as a marker of long-term retention of self-referred material.

4.3 Final conclusion

In conclusion, the present enquiry added to existing evidence that the self has an impact on the cognitive processes of attention and memory. Specifically, using ownership as a means of triggering self-referential encoding, an attentional bias toward self-referred items was found, which was argued to facilitate elaborative encoding of said items, resulting in retrieval accompanied by recollective experience. Future research could investigate whether self-specific brain structures support the retrieval of self-owned items in the shopping paradigm, for a thorough account of where and how self-reference triggered by ownership impacts on memory and, particularly, on its recollection component.

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Appendices

Appendix A.

Response numbers, proportion correct and sensitivity index scores for the test phase of Experiment 1.

Participant Number	*Hits Self/Other*	*Misses Self/Other*	*CRs (FAs)*	*NR*	*Correct Tot*	*Correct Self*	*Correct Other*	*Correct New*	*d'*
1[a]	38 16/22	119 64/55	70 (10)	3	0.46	0.20	0.29	0.88	0.44
2	121 59/62	37 21/16	60 (16)	6	0.77	0.74	0.79	0.79	1.54
6	109 62/47	51 18/33	68 (12)	0	0.74	0.78	0.59	0.85	1.51
7	111 54/57	47 25/22	62 (18)	2	0.73	0.68	0.72	0.78	1.26
9	105 59/46	54 21/32	61 (16)	4	0.70	0.74	0.59	0.79	1.24
10	96 57/39	64 23/41	69 (11)	0	0.69	0.71	0.49	0.86	1.34
11	135 76/59	25 4/21	69 (11)	0	0.85	0.95	0.74	0.86	2.10
12	139 67/72	21 13/8	74 (6)	0	0.89	0.84	0.90	0.93	2.56
13	83 46/37	77 34/43	69 (10)	1	0.64	0.58	0.46	0.87	1.20
14	78 36/42	81 43/48	73 (7)	1	0.63	0.46	0.53	0.91	1.32
15[a]	52 21/31	108 59/49	69 (11)	0	0.50	0.26	0.39	0.86	0.64
16	141 71/70	17 7/10	73 (7)	2	0.90	0.91	0.88	0.90	2.54
17[a]	69 34/45	84 34/50	56 (21)	10	0.54	0.44	0.47	0.73	0.46
18	127 63/64	33 17/16	70 (10)	0	0.82	0.79	0.80	0.88	1.97
19[a]	73 44/29	84 34/50	67 (12)	4	0.59	0.56	0.37	0.85	0.93
20	95 52/43	65 28/37	79 (1)	0	0.73	0.65	0.54	0.99	2.48
21[a]	78 41/37	82 39/43	65 (15)	0	0.60	0.51	0.46	0.81	0.86
23	113 57/56	47 23/24	69 (11)	0	0.76	0.71	0.70	0.86	1.63
24[b]	101 47/54	59 33/26	74 (5)	1	0.73	0.59	0.68	0.94	1.87
25	122 61/61	38 19/19	60 (20)	0	0.76	0.76	0.76	0.75	1.39
26[a]	65 36/29	95 44/51	68 (11)	1	0.56	0.45	0.36	0.86	0.85
27	129 64/65	26 15/11	73 (5)	7	0.87	0.81	0.86	0.94	2.40

28	125	35	59	1	0.77	0.73	0.84	0.75	1.45
	58/67	22/13	(20)						
29	134	26	80	0	0.89	0.89	0.79	1.00	3.48[c]
	71/63	9/17	(0)						
30	113	45	54	5	0.71	0.72	0.71	0.70	1.10
	57/56	22/23	(23)						
31	135	25	64	0	0.83	0.88	0.81	0.80	1.85
	70/65	10/15	(16)						
32	106	54	61	0	0.70	0.66	0.66	0.76	1.13
	53/53	27/27	(19)						
33[b]	91	67	78	2	0.71	0.63	0.53	0.98	2.13
	49/42	29/38	(2)						
34	113	47	72	0	0.77	0.81	0.60	0.90	1.82
	65/48	15/32	(8)						
35	151	9	76	1	0.95	1.00	0.89	0.96	3.37
	80/71	0/9	(3)						
36	91	69	66	0	0.65	0.53	0.61	0.83	1.11
	42/49	38/31	(14)						
37[a]	56	103	65	1	0.51	0.29	0.41	0.81	0.50
	23/33	56/47	(15)						

Note. Responses for participants number 3, 4, and 5 were absent; participants number 8 and 22 were excluded from the analysis due to artefact rejection. CRs = Correct Rejections; FAs = False Alarms; NR = No Response; *d'* = sensitivity index scores.

[a] Participants with a d' score of less than 1 were excluded from the analysis (n = 7). [b] Participants whose responses were missing only for the encoding task (n = 2) were included in the analysis of ERP data at encoding, and both behavioural and ERP data at test, on the basis of their good test performance, as measured by *d'* and overall accuracy. [c] FA-rate was adjusted to 0.5 for the purpose of estimating *d'*.

Appendix B.

Written R-K task instructions for Experiment 2 adapted from Gardiner & Richardson-Klavehn (2000).

In this test you will see a series of pictures of items, one item at a time. Some of the items are those that you've seen in the shopping task. Others are not. You will be asked to recognise the items that you have seen already.

Recognition memory is associated with two different kinds of awareness. Quite often recognition brings back to mind something you recollect about what it is that you recognise, as when, for example, you recognise someone's face, and perhaps remember talking to this person at a party the previous night. At other times recognition brings nothing back to mind about what it is you recognise, as when, for example, you are confident that you recognise someone, and you know you recognise them, because of strong feelings or familiarity, but you have no recollection of seeing this person before. You do not remember anything about them.

The same kinds of awareness are associated with recognising the items you've seen in the previous task. Sometimes when you recognise an item as one you've seen already, recognition will bring back to mind something you remember thinking about when the item appeared then. You recollect something you consciously experienced at that time. But sometimes recognising an item as one you've seen during the sorting task will not bring back to mind anything you remember about seeing it then. Instead, the item will seem familiar, so that you feel confident it was one you've already seen, even though you don't recollect anything you experienced when you saw it then.

For each item, click the YES button if you recognise the item as one you've seen in the previous task, and click the NO button if you do not think the item was one you've seen already.

For each item that you recognise, after you have clicked the YES button, please then click the REMEMBER button, if recognition is accompanied by some recollective experience, or the KNOW button, if recognition is accompanied by strong feelings of familiarity in the absence of any recollective experience.

There might also be times when, after clicking the YES button, you realise you did not remember the item, nor did it seem familiar. If your YES response is really just a guess, please then click the GUESS button.

The experimenter will now ask you to explain to them, in your own words, what the difference between remembering and knowing is, to make sure you have understood the purpose of the task.

Appendix C.

Number of responses for the memory test in Experiment 2.

Participant	*SH*	*SR*	*SK*	*SG*	*SM*	*OH*	*OR*	*OK*	*OG*	*OM*	*CR*	*FA*	*NR*	*NK*	*NG*
1[a]	32	18	10	4	63	27	17	6	3	68	84	11	3	6	2
2	87	76	8	3	8	64	6	57	1	31	83	12	1	2	9
3	67	39	28	0	28	42	16	26	0	53	92	3	0	3	0
4	82	44	38	0	13	69	36	33	0	26	88	7	0	7	0
5	79	69	9	1	16	69	52	15	2	26	64	31	13	17	1
6[a]	21	5	16	0	74	23	7	15	0	72	84	11	0	10	1
7	47	28	19	0	48	50	32	17	1	45	88	7	0	7	0
8	70	25	45	0	25	49	8	41	0	46	91	4	0	4	0
9	25	18	3	4	70	31	20	6	5	64	88	7	5	1	1
10	42	23	19	0	53	42	21	21	0	53	61	34	14	19	1
11	32	18	3	10	63	29	15	8	6	66	83	12	6	3	3
12	48	32	16	0	47	46	26	20	0	49	78	17	4	13	0
13[a]	15	7	8	0	80	20	13	7	0	75	87	8	6	2	0
14	38	30	2	4	57	43	28	4	11	52	89	6	1	1	4
15[b]	57	—	—	—	38	50	—	—	—	45	91	4	—	—	—
16	32	15	17	0	63	38	18	20	0	57	89	6	6	0	0
17	40	17	14	9	55	34	15	14	4	61	74	21	13	1	7
18[b]	62	—	—	—	33	64	—	—	—	28	71	24	—	—	—
19[c]	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
20[c]	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
21	41	28	8	5	54	51	38	10	3	44	70	25	20	3	2
22[a]	84	45	27	12	11	82	32	30	20	13	30	65	3	23	38
23	81	70	11	0	14	56	36	13	7	39	89	6	0	5	1
24	68	59	9	0	27	69	55	14	0	26	92	3	0	3	0
25	66	45	19	2	29	69	42	21	6	26	80	15	1	8	6
26[a]	21	8	10	1	74	21	5	15	0	73	91	4	2	2	0
27[b]	49	—	—	—	46	50	—	—	—	45	93	2	—	—	—
28	34	20	14	0	61	34	16	18	0	61	87	8	1	7	0
29[b]	71	—	—	—	24	68	—	—	—	27	86	8	—	—	—
30[a]	20	15	2	1	75	21	9	8	4	74	88	7	6	0	1
31	73	54	18	1	22	54	19	35	0	41	94	1	1	0	0
32	62	28	34	0	33	47	13	33	0	48	75	19	0	19	0
33[a]	22	13	6	3	73	25	19	4	2	70	86	9	6	2	1
34	72	34	28	10	23	65	40	13	12	30	92	3	1	0	2
35	46	28	17	0	49	42	22	19	1	53	59	36	9	26	0
36	56	27	22	7	39	43	25	13	5	52	82	13	2	8	3
37[c]	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
38	50	22	27	1	45	45	16	27	2	50	71	24	5	18	1
39	63	44	18	1	32	51	30	19	2	44	74	21	6	15	0
40	35	12	23	0	60	24	12	12	0	71	86	9	2	7	0
41[a]	38	8	30	0	57	43	8	35	0	52	62	33	9	23	1
42	70	43	19	8	25	64	20	32	12	31	85	10	0	1	9

43	75	61	11	3	20	68	58	9	1	27	87	8	2	4	2
44	55	37	12	6	40	72	56	12	4	23	68	27	4	19	4
45	60	24	30	6	35	58	20	31	7	37	91	4	0	1	3
46	62	37	24	1	33	59	34	25	0	36	91	4	0	4	0
47	43	36	5	2	52	56	48	5	3	39	76	19	12	2	5
48[a]	18	6	9	3	77	12	7	5	0	83	82	13	2	9	2
49	43	22	20	1	52	48	24	23	1	47	75	20	0	20	0
50	56	21	34	1	39	60	26	34	0	35	62	33	2	31	0
51	57	33	18	6	38	52	29	18	5	43	67	28	23	1	4
52	38	19	18	1	57	42	16	22	4	53	84	11	1	6	4

Note. S= Self; O=Other; N=New; H=Hit; M=Miss; R=Remember; K=Know; G=Guess; CR = Correct Rejection; FA = False Alarm.

[a]Participant excluded from the memory analysis during data processing. [b]Participant excluded from the memory awareness analysis only due to recording failure resulting in lack of data. [c]Participant did not complete the experiment and was not included in any analysis.